Final Report
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Routine High-Resolution Forecasts/Analyses for the Pacific Disaster Center: User Manual

http://ecpc.ucsd.edu/projects/PDC
http://www.mhpcc.edu/~wswx/

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Summary
Enclosed herein is our HWCMO user manual. This manual constitutes the final report for our NASA/PDC grant, NASA NAG5-8730, "Routine High Resolution Forecasts/Analysis for the Pacific Disaster Center".

Since the beginning of the grant, we have routinely provided experimental high resolution forecasts from the RSM/MSM for the Hawaii Islands, while working to upgrade the system to include: (1) a more robust input of NCEP analyses directly from NCEP; (2) higher vertical resolution, with increased forecast accuracy; (3) faster delivery of forecast products and extension of initial 1-day forecasts to 2 days; (4) augmentation of our basic meteorological and simplified fireweather forecasts to firedanger and drought forecasts; (5) additional meteorological forecasts with an alternate mesoscale model (MM5); and (6) the feasibility of using our modeling system to work in higher-resolution domains and other regions.

In this user manual, we provide a general overview of the operational system and the mesoscale models as well as more detailed descriptions of the models. A detailed description of daily operations and a cost analysis is also provided. Evaluations of the models are included although it should be noted that model evaluation is a continuing process and as potential problems are identified, these can be used as the basis for making model improvements. Finally, we include our previously submitted answers to particular PDC questions (Appendix V).

All of our initially proposed objectives have basically been met. In fact, a number of useful applications (VOG, air pollution transport) are already utilizing our experimental output and we believe there are a number of other applications that could make use of our routine forecast/analysis products. Still, work still remains to be done to further develop this experimental weather, climate, fire danger and drought prediction system. In short, we would like to be a part of a future PDC team, if at all possible, to further develop and apply the system for the Hawaiian and other Pacific Islands as well as the entire Pacific Basin.

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1. Introduction

The goal of our Hawaii Weather and Climate Modeling Ohana (HWCMO) PDC project was to develop and routinely deliver high resolution forecasts/analyses to PDC from experimental Regional and Mesoscale Spectral model (RSM/MSM) forecasts already being run at the Maui High Performance Computing Center (MHPCC) while enhancing and further developing the HWCMO forecast/analysis system to include drought and fire danger forecasts as well as an alternative Mesoscale Modeling System (MM5).

The RSM/MSM currently makes routine forecasts out to 48 hours every day and has shown the capability of making even longer forecasts (out to 72 hours) depending upon available computer time. The MM5, which was developed for Hawaii by this contract has shown the capability of also making reasonable forecasts for at least 30 hours. Both mesoscale models are capable of being set up for additional regional domains although some effort would be needed to acquire appropriate land surface conditions such as orography and vegetation as well as a local user community for ongoing forecast evaluation.

The driving global forecasts come from the National Centers for Environmental Prediction (NCEP) global (aviation) forecasts, which were initially passed through the Scripps Experimental Climate Prediction Center (ECPC) but are now obtained directly from the National Centers for Environmental Prediction (NCEP) anonymous ftp site. Longer range forecasts (more than 72 hours) would need to use the Scripps Experimental Climate Prediction Center (ECPC) global forecasts, which are currently run daily out to 7 days and weekly out to 12 weeks. ECPC forecasts also provide larger-scale (time and space) guidance for the Pacific Basin.

HWCMO standard meteorological output includes precipitation, temperature, wind, relative humidity and a simplified fire weather index. A new Hawaii fire danger code was developed for PDC that makes use of the digital data from these forecasts as well as satellite observations of fuels and fuel stress to provide additional forecasts of various fire danger and drought indices.

Since the beginning of this contract, this output has been made available to the Pacific Disaster Center (PDC) as raw binary files, as GIS text files, and as images, which are produced at our web site (http://www.mhpcc.edu/~wswx/). At PDC's request, GIS files are now being sent to PDC's anonymous ftp site daily. This output will continue to the end of the contract.

In this PDC user manual, we provide an overview (Sec. 2) of the current forecast systems installed at MHPCC, which includes the MSM, Fire Danger, and MM5 codes. We then describe some of the ongoing evaluations of the system (Sec. 3). A summary and some avenues for further research are provided in Sec. 4. More detailed descriptions of each of the individual components of the HWCMO system are provided in the User Manual Appendices: Appendix I is description of the HWCMO system at MHPCC. Appendix II is the RSM/MSM/CVS user manual, which is also available from the ECPC RSM web site http://ecpc.ucsd.edu/projects/RSM/. Appendix III is the Hawaii Fire Danger User manual. Appendix IV provides more details about the Hawaii MM5 although the more general user manual for this model is available at NCAR, where the main code currently resides. Finally, Appendix V provides answers to specific PDC questions about our system.

2. Model Overviews

Our initial HWCMO mesoscale modeling system was based upon a nonhydrostatic version of regional spectral model (RSM; the nonhydrostatic version, mesoscale spectral model, is referred to as MSM) being developed at the National Centers for Environmental Prediction (NCEP) and at the Scripps Experimental Climate Prediction Center (ECPC). During this current PDC grant (9/1/1999-8/31/2001), we augmented this single mesoscale modeling system with the NCAR/Penn St. mesoscale model (MM5).

The RSM output currently provides the basic meteorological forecasts and input to a new Hawaii Fire Danger Code developed for PDC. The new Hawaii Fire Danger Rating System is based on the National Fire Danger Rating System (NFDRS) that has been used on the continental United States since 1978 (Deeming and others, 1978).

The current resolution of the forecasts depends upon domain size and model. At the longest time scales and largest space scales the Scripps ECPC makes global forecasts (200 km resolution) out to 7 days every day and out to 12 weeks every weekend. These forecasts are equivalent, but at lower resolution (L18T63) than the NCEP aviation forecasts (L42T170), which are now being used to drive the Hawaii forecasts (48 hours for the MSM and 30 hours for MM5). However, if longer term forecasts (beyond 3 days) are desired, then the ECPC forecasts are available. (For example, the ECPC makes 7 day regional forecasts every day and 16 week regional forecasts every weekend for many other regions of the world (US, US SW, CA, BZ) at resolutions of 50-10 kms. For Hawaii, where only 2-day forecasts are currently being done, we use the higher resolution aviation forecasts (initialized at 00 UTC) to first drive a 10 km MSM for all of the Hawaiian Islands (first nest). A similar 48 hour forecast with a 10 km RSM is made by NCEP for the National Weather Service (NWS) in Hawaii. Besides using the nonhydrostatic model (MSM) another difference between our experimental HWCMO model and the NWS model is that we further resolve individual island counties at still higher resolution in a second nest. For the RSM the grid resolutions are: Hawaii, 4kms; Maui, 3 kms; Oahu, 2 kms; Kauai, 2 kms. All nests now have 42 levels in order to match the levels of the current Aviation forecasts.

As for the MM5 forecasts, the original aviation forecasts (initialized at 12 UTC) drive a low resolution model (27 kms, 18 levels) for a large-scale domain. Higher resolution models are then nested within and include: all island (9 kms, 18 levels), and then a third nest is included for individual counties (3 kms, 18 levels).

RSM and MM5 image output are available on the HWCMO site and GIS text files are also available on disk which could be used by PDC for its own displays as well as basic input to drive various PDC application models. In fact, some of the data are ftp'd daily to PDC. The digital output is also archived on a disk at MHPCC for 5 days before being transferred to the mass storage. Additional images and output from the Scripps global forecasts are also available upon request. All of this output is used to drive firedanger and other application models (e.g. vog).

In this section we provide an overview of the models (MSM, Fire Danger Code, MM5) and then provide more details about the HWCMO models in Appendices II-IV. In addition, Appendix I provides a complete description of the operational environment at MHPCC for the RSM and MM5.

2.1 RSM/MSM/CVS Overview

The hydrostatic regional spectral model and the corresponding nonhydrostatic mesoscale spectral model (RSM/MSM) are based upon the global spectral model (GSM, or medium range forecast, MRF) model used at NCEP for making the four times daily global data assimilation system (GDAS) analysis and for making the medium range forecast (MRF and Aviation) predictions. Since the RSM/MSM, developed by *Juang and Kanamitsu* (1994; see also *Juang*, 1997) are regional extensions to the GSM used in the NCEP operational analysis, in principle they provide an almost seamless transition between the operational analyses and global forecasts and higher resolution regions of interest. Another advantage, according to *Hong and Leetma* (1999), is that the RSM does not have the same restrictions on nesting size that other regional climate models seem to have and smaller nests can be embedded within the large-scale reanalysis without noticeable errors or influences. The RSM has been used for a number of studies over the US and elsewhere (see http://ecpc.ucsd.edu/projects/RSM/ for a list of over 50 recent references).

Both the GSM and RSM/MSM use the same primitive hydrostatic system of virtual temperature, humidity, surface pressure and mass continuity prognostic equations on terrain-following sigma (sigma is defined as the ratio of the ambient pressure to surface pressure) coordinates. The MSM also uses the same coordinate system but also includes additional terms relevant to nonhydrostatic motions. Therefore, in the absence of any regional forcing, (and intrinsic internal dynamics, any significant physical parameterization differences, and significant spatial resolution) the total RSM/MSM solution should be identical to the GSM solution. A minor structural difference is that the GSM utilizes vorticity, divergence equations, whereas the RSM/MSM utilizes momentum equations in order to have simpler lateral boundary conditions. The GSM and RSM/MSM horizontal basis functions are also different. The GSM uses spherical harmonics with a triangular truncation of 62 (T62) whereas the RSM/MSM use cosine or sine waves to represent regional perturbations about the imposed global scale base fields on the regional grids. The double Fourier spectral representations are carefully chosen so that the normal wind perturbations are anti-symmetric about the lateral boundary. Other model scalar variables (i.e. virtual temperature, specific humidity, and surface log pressure) are symmetric perturbations.

The first part of an RSM/MSM forecast or simulation involves the integration of the GSM, or the use of the analysis, for a nesting period based upon the large-scale output. Here, the RSM/MSM predict regional deviations from the large-scale atmosphere base fields, which are linearly interpolated in time between the two reanalysis output periods (6 hours). The non-linear advection is first computed at the model grid points by transforming the global and regional spectral components to the regional grid. The global quantities are transformed to the global grid and then bilinearly interpolated to the regional grid; the regional quantities are exactly transformed. These calculations are almost exact (except for the interpolation error for the global quantities) and thus, like the global model, the regional model is free of aliasing and phase error. The linearly interpolated global-scale tendency is then removed, so that, in effect, only the portion affecting the regional perturbation is retained. At the horizontal boundaries, the perturbation amplitude approaches zero by a damping function increasing rapidly toward the lateral boundary, which ensures that the boundary tendencies are similar to the original GSM tendencies and features. A semi-implicit time integration scheme is employed to suppress computational modes and also to allow the use of longer time integration steps.

We have recently developed a new version of the Regional Spectral Model (RSM and eventually MSM) to be managed by Concurrent Versions System (CVS) and controlled by configure files and Makefile system.° This new RSM/MSM/CVS system is designed to have the same structure as the NCEP's Global Spectral Model (GSM), which is also managed by the CVS, so that the latest updates of model physics in the GSM/CVS system can be directly incorporated into the RSM/MSM/CVS system. The surface fields in the RSM/MSM/CVS such as topography, sea surface temperature, surface roughness, and surface albedo are obtained directly from the higher resolution observation or climatological data rather than interpolated from the lower resolution global analysis or forecast data.° The RSM/MSM/CVS has a parallel computing capability and the speed-up is about 75% per processor.° Users can easily download and update the model code through the CVS. Details can be found at http://www.cvs.home.org.°
°

The purpose of the RSM/MSM/CVS user manual (Appendix II) is to provide the users with entry-level information for the model system installation, the model library and utility, the model code and input/output structure, and the model integration and run procedure.° The information for the model dynamics and physics is not included in the current manual but can be found on the RSM home page (http://ecpc.ucsd.edu/projects/RSM).° The manual is composed of five subsections as follows:

* CVS system
* Model system structure
* Model integration road map
* Model IO
* Setting-up experiment and model run procedure

In the CVS system section, the CVS installation and simple usage as well as the RSM/MSM installation using the CVS are described. The structure of model directories, libraries and utilities, as well as the source code is described in the Model system structure section.° The description for the model integration procedure and model input/output variables and postprocessing can be found in the Model integration Road Map and Model IO sections, respectively.° Setting model parameters for an experiment and the run procedure are described in the Setting-up experiment and model run procedure section

References

Hong, S. and A. Leetmaa, An evaluation of the NCEP RSM for regional climate modeling. (in press), *J. Climate*, 1999.

Juang, H. and M. Kanamitsu, The NMC nested regional spectral model. *Mon. Wea. Rev.*, 122, 3-26, 1994.

Juang, H., S. Hong, and M. Kanamitsu, The NMC nested regional spectral model. An update. *Bull. Amer. Meteor. Soc.*, 78, 2125-2143, 1997

2.2 Hawaii Fire Danger Overview

The Hawaii Fire Danger Rating System is based on the National Fire Danger Rating System (NFDRS) that has been used on the continental United States since 1978 (Deeming and others, 1978). To be used effectively, one must know what the NFDRS will and will not do. The basic principles of the NFDRS are as follows:

1. The NFDRS relates only to the potential of a fire that spreads through continuous ground fuels, without spotting.

2. The system addresses only those aspects of fire control strategy affected by fire occurrence and behavior

3. The ratings are relative, not absolute.

4. Fire danger is rated from a worst case approach by virtue of using afternoon weather observations.

There are three basic inputs to computing fire danger rating – weather, topography and fuels. Because fire danger is a cumulative phenomenon, weather is the driver in terms of producing seasonal changes in fire danger estimates. Topography is used to reflect the fact that fire burns faster upslope than on flat ground. Vegetation is deemed to be fuel for fire danger rating purposes. Twenty NFDRS fuel models represent the vegetation types across the U.S., defining fuel characteristics such as depth, load by live and dead classes, heat content, fuel particle size, etc. These basic inputs are converted into various fire danger indexes by processing them through a modified version of the fire spread model developed by Rothermel (197?).

The standard NFDRS uses weather data measured at many weather stations and is assumed to apply to a large, vaguely defined area surrounding each weather station. Vegetation (fuel) types and slope are defined for each weather station and assumed to apply to the same surrounding area. The Hawaii Fire Danger Rating System (HFDRS) differs from the National Fire Danger Rating System in that the HFDRS calculations are done using gridded fuels, weather and topography data. This provides the opportunity to improve on these input data. The fuels data for the HFDRS is defined at 1km spatial resolution, while the weather data is at 2, 3, or 4 km resolution, replicated to 1km resolution. The higher resolution fuels data permits display of more fire danger variability through the assumption that the actual weather parameter values are reasonably constant within a 4, 9, or 16 square km area.

Figure 1 illustrates the structure of the HFDRS. Individual island fuel maps were derived from seasonal NDVI profiles of Hawaii vegetation, classified into 26 categories, then translated to NFDR fuel models with the aid of local fire managers. These are static maps that define the fuel model to be used for each pixel. In development of the NFDRS, it was found that seasonal moisture changes of large, approximately 6 inch diameter, dead wood provided a mechanism for calculating the moisture of live vegetation. The fire danger output maps are posted on the internet for easy user access.

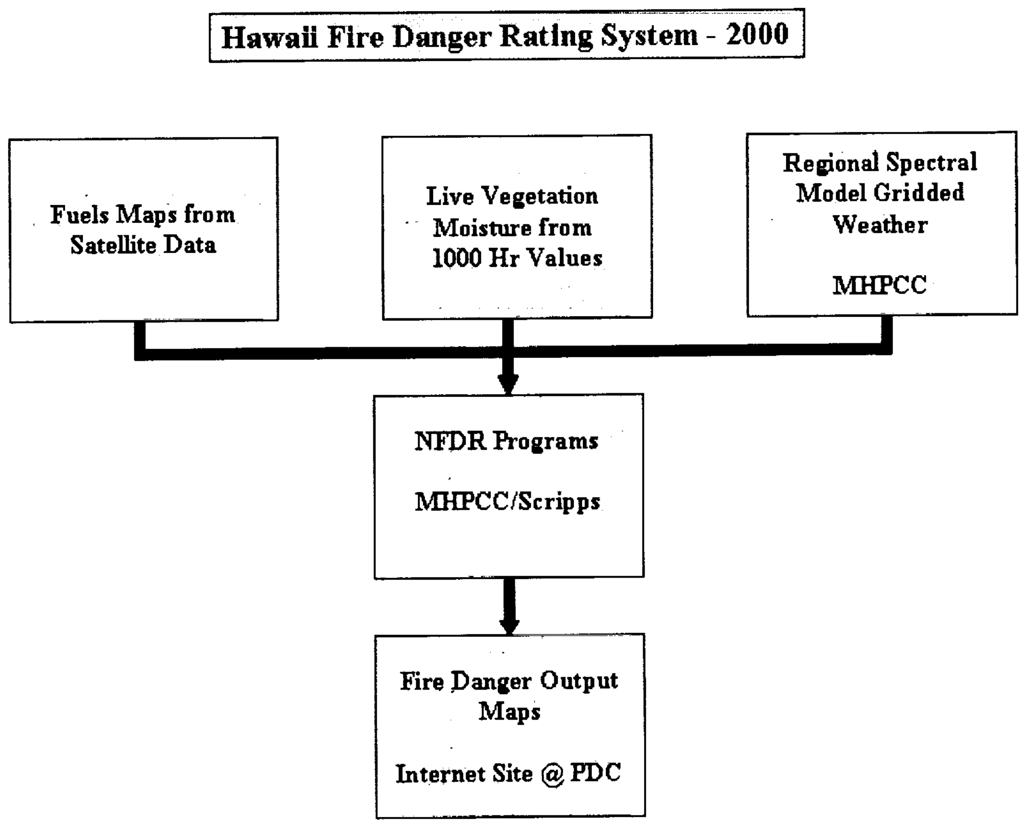

Figure 1. Structure of the Hawaii Fire Danger Rating System

The outputs of the HFDRS are as follows:

1. Spread Component – A rating of the forward rate of spread at the head of a fire.

2. Energy Release Component – A number related to the available energy (Btu's per square foot within the flaming front at the head of a fire.

3. Burning Index – A number related to the contribution of fire behavior to the effort of containing a fire.

4. Ignition Component – A rating of the probability that a firebrand will cause a fire requiring suppression action.

5. Keetch-Byram Drought Index – A number (0-800) defining how many hundredths of an inch of water is required to saturate the soil. This index was not part of the original NFDRS, but was added in a 1988 revision.

2.3 MM5 Overview

The PSU/NCAR mesoscale model, version 5 (MM5), is a limited-area, nonhydrostatic, terrain-following sigma-coordinate model designed to simulate or predict mesoscale and regional-scale atmospheric circulation. It has been developed at Pennsylvania State University and the National Center for Atmospheric Research (NCAR) as a community mesoscale model and is continuously being improved by contributions from users at several universities and government laboratories. It has undergone many changes designed to broaden its usage. These include (i) a multiple-nest capability; (ii) nonhydrostatic dynamics, which allows the model to be applied at a few-kilometer scale; (iii) multitasking capability on shared- and distributed-memory machines; (iv) a four-dimensional data-assimilation capability; and (v) more physics options.

The model is supported by several auxiliary programs. Terrestrial and isobaric meteorological data are horizontally interpolated (programs TERRAIN and REGRID) from a latitude-longitude mesh to a variable high-resolution domain on either a Mercator, Lambert conformal, or polar stereographic projection. Since the interpolation does not provide mesoscale detail, the interpolated data may be enhanced (program RAWINS or little_r) with observations from the standard network of surface and rawinsonde stations using either a successive-scan Cressman technique or multiquadric scheme. Program INTERPF performs the vertical interpolation from pressure levels to the sigma coordinate system of MM5. Sigma surfaces near the ground closely follow the terrain, and the higher-level sigma surfaces tend to approximate isobaric surfaces. Since the vertical and horizontal resolution and domain size are variable, the modeling package programs employ parameterized dimensions requiring a variable amount of core memory. Since MM5 is a regional model, it requires initial conditions and lateral boundary conditions to run. One needs gridded data to cover the entire time period that the model is integrated.

Features of the Modeling System (adapted from www.mmm.ucar.edu/mm5/mm5-home.html) are:

- Globally re-locatable
  - Three map projections:
    - Polar stereographic;
    - Lambert conformal;
    - Mercator.
  - Variable resolution terrain elevation, landuse, soil type, deep soil temperature, vegetation fraction, and land-water mask datasets are provided (the new global 30 sec terrain data may be obtained from USGS anonymous ftp site).
- Flexible and multiple nesting capability
  - Can be configured to run from global scale down to cloud scale in one model
  - Can be run in both 2-way and 1-way nesting mode:
    - 2-way: multiple nests and moving nests
    - 1-way: fine-mesh model driven by coarse-mesh model
  - Nest domain can start and stop at any time.
  - Nest terrain file may be input at the time of nest start-up in the model.
- Real-data inputs
  - Use routine observations
  - Couple with global models and other regional models

- Non-hydrostatic dynamic framework.
- Terrain-following vertical coordinates.
- Choices of advanced physical parameterization.
- Four-dimensional data assimilation system via nudging.
- Adjoint model and 3DVAR (under development).
- The MM5 modeling system runs on various computer platforms
    - shared-memory machines
    - Parallelized on distributed-memory machines
- Well-documented, and user-support available.

<u>MM5 Model Physics Options</u>

- Precipitation physics
    - Cumulus parameterization schemes:
        - Anthes-Kuo
        - Grell
        - Kain-Fritsch
        - Fritsch-Chappell
        - Betts-Miller
        - Arakawa-Schubert
    - Resolvable-scale microphysics schemes:
        - Removal of supersaturation
        - Hsie's warm rain scheme
        - Dudhia's simple ice scheme
        - Reisner's mixed-phase scheme
        - Reisner's mixed-phase scheme with graupel
        - NASA/Goddard microphysics with hail/graupel
        - Schultz mixed-phase scheme with graupel
- Planetary boundary layer process parameterization
    - Bulk formula
    - Blackadar scheme
    - Burk-Thompson (Mellor-Yamada 1.5-order/level-2.5 scheme)
    - Eta scheme (Janjic, 1990, 1994)
    - MRF scheme (Hong and Pan 1996)
    - Gayno-Seaman scheme (Gayno 1994)
- Surface layer precess parameterization
    - fluxes of momentum, sensible and latent heat
    - ground temperature prediction using energy balance equation
    - variable land use catagories (defaults are 13, 16 and 24)
    - 5-layer soil model and OSU land-surface model (V3 only)
- Atmospheric radiation schemes
    - Simple cooling
    - Dudhia's long- and short-wave radiation scheme
    - NCAR/CCM2 radiation scheme
    - RRTM long-wave radiation scheme (Mlawer et al., 1997)

3. Model Evaluations

In this section, we describe some ongoing evaluations of the MSM and the new Hawaii Fire Danger Code. The MM5 has not yet been evaluated, since it was brought online only near the end of the contract. However, it should be noted that preliminary comparisons have not indicated any clear superiority of any regional model and there is in fact some evidence that probability forecasts from model ensembles, which include different models, may be superior to single forecasts or probability from single models. Depending on resources, different models can be optimally combined to give superior forecasts, much like current weather services, who have access to not only their own forecasts but also forecasts from other national weather services, will make use of both. However, if resources are limited, it may be better for PDC to just pick one model that can adequately do at least the required analysis job. In that regard, our RSM/MSM system has now been more thoroughly tested and is being used to drive the fire danger and drought predictions. Thus we would have the greatest confidence in the RSM/MSM to continue to carry out all of our now routine forecasts of meteorological variables and fire danger variables.

3.1 RSM/MSM Evaluations

Two types of model evaluations for the RSM/MSM are described here. These include: (3a.1) an evaluation of the overall model climatology and forecast skill in comparison to available observations; (3a.2) a more detailed look at a high resolution case study for Oahu, which was developed as part of a graduate student thesis (Funayama 2001). The latter study was undertaken in order to understand how resolution might affect the solution.

3.1.1 RSM/MSM Climatology

To provide some background for the subsequent model comparisons to the station observations, we first show the annual mean model climatology developed during the current PDC contract. In particular, all easily available 24-hour forecasts (output every 3hours from 3h to 24h) were averaged for each month and then all available months were averaged to form an annual mean. It should be noted that lthough the forecasts were routinely made since the beginning of the contract, serious archival did not occur until the bugs in the output storage and transfer had been eliminated, and we now have fairly clean (albeit still a number of missing forecasts) data from Dec. 1999-present. The reasons for the missing forecast days were that serious disruptions occurred as the software and hardware systems were extended and modified and some of our preliminary fail-safe mechanisms did not always work. Each missing period has taught us a valuable operational lesson, which we tried to subsequently correct, and the current system has operated unfailingly since April 2000. Despite the missing days, we were still able to acquire enough output data to make meaningful model climatology and this climatology along with the comparison to the available meager observations are described below.

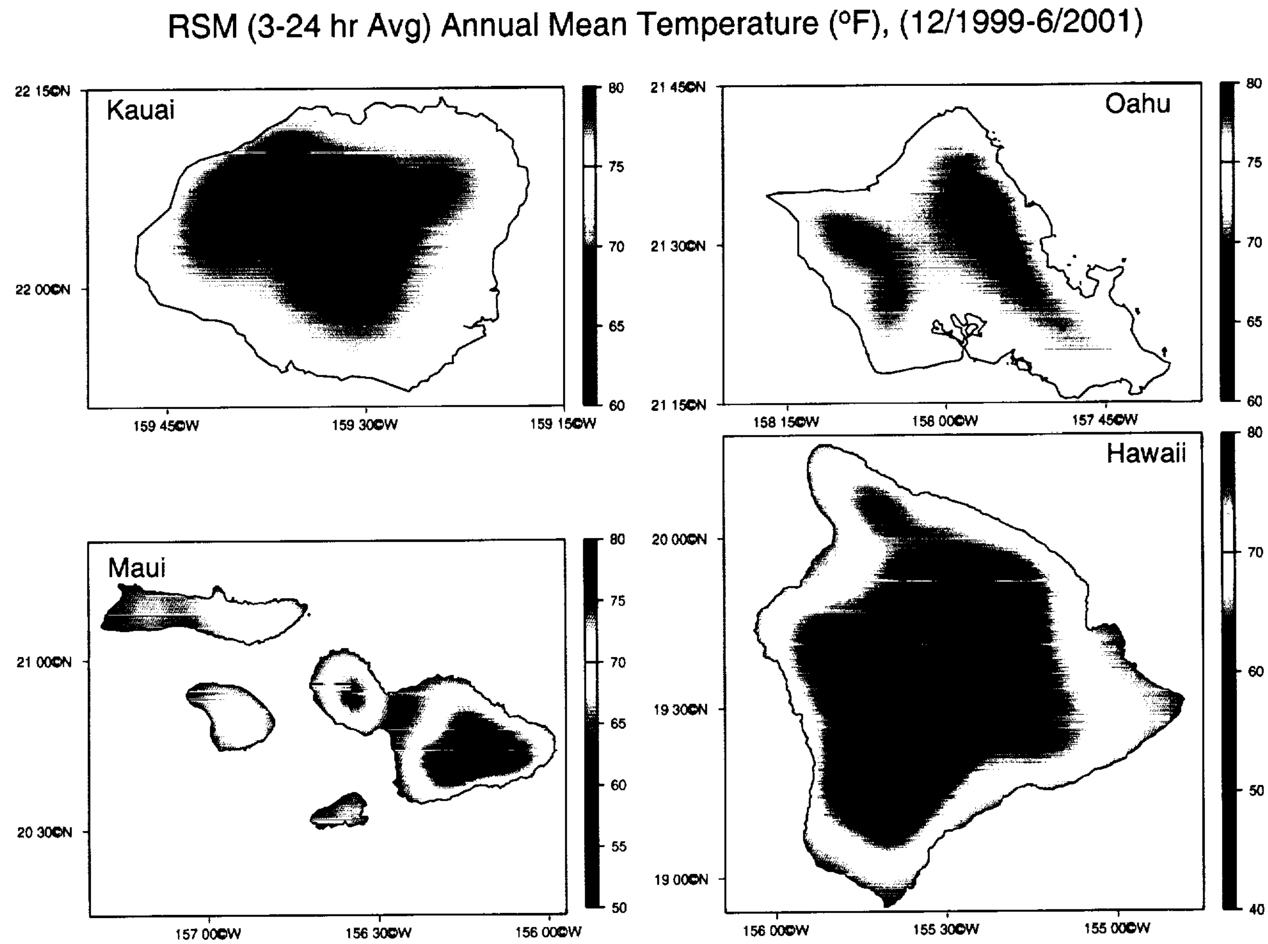

Fig. 1 Annual mean average temperature (F).

Fig. 1 shows the annual mean average temperature for the islands. Note the lapse rate effect in that higher elevations have lower temperatures, on average. This is a characteristic elevation effect although the Hawaii Islands tend to have greater contrasts over shorter distances than most places. Note that the central valley of Maui, as well as Molokai, Lanai, and Kahoolawe, and the coastal regions of Hawaii have some of the highest temperatures whereas the lowest temperatures occur at the top of the volcanic peaks.

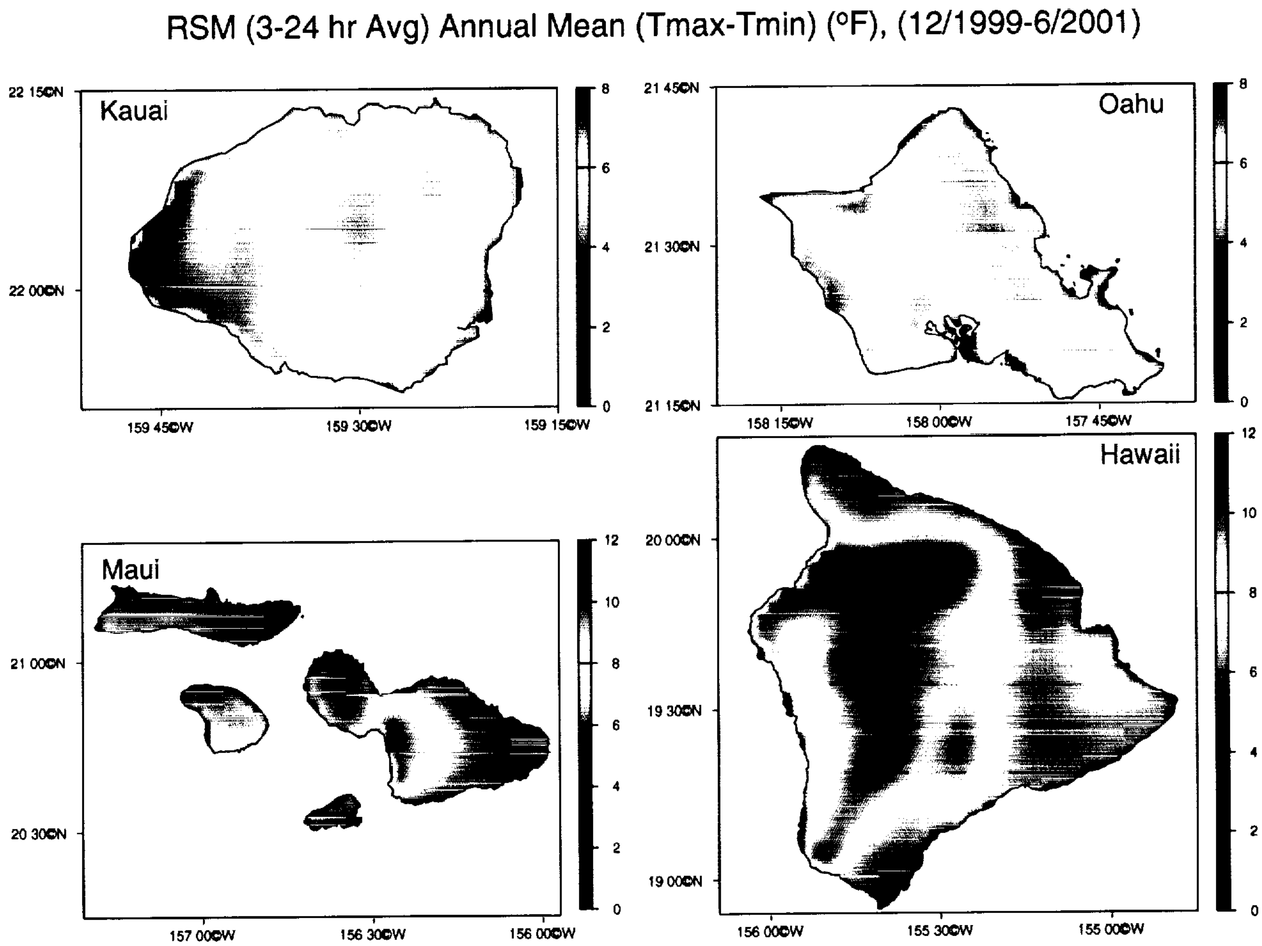

Fig. 2 Average diurnal temperature range.

Fig. 2 shows the diurnal temperature range for the islands, which is greatest on the lee side of the mountain ranges. The diurnal temperature range can be as large as 10 K, especially on the leeward side of Kauai and Hawaii. As will be shown later, this diurnal temperature range may be underestimated since the MSM high temperatures tend to be low and the low temperatures tend to be high in comparison to observations.

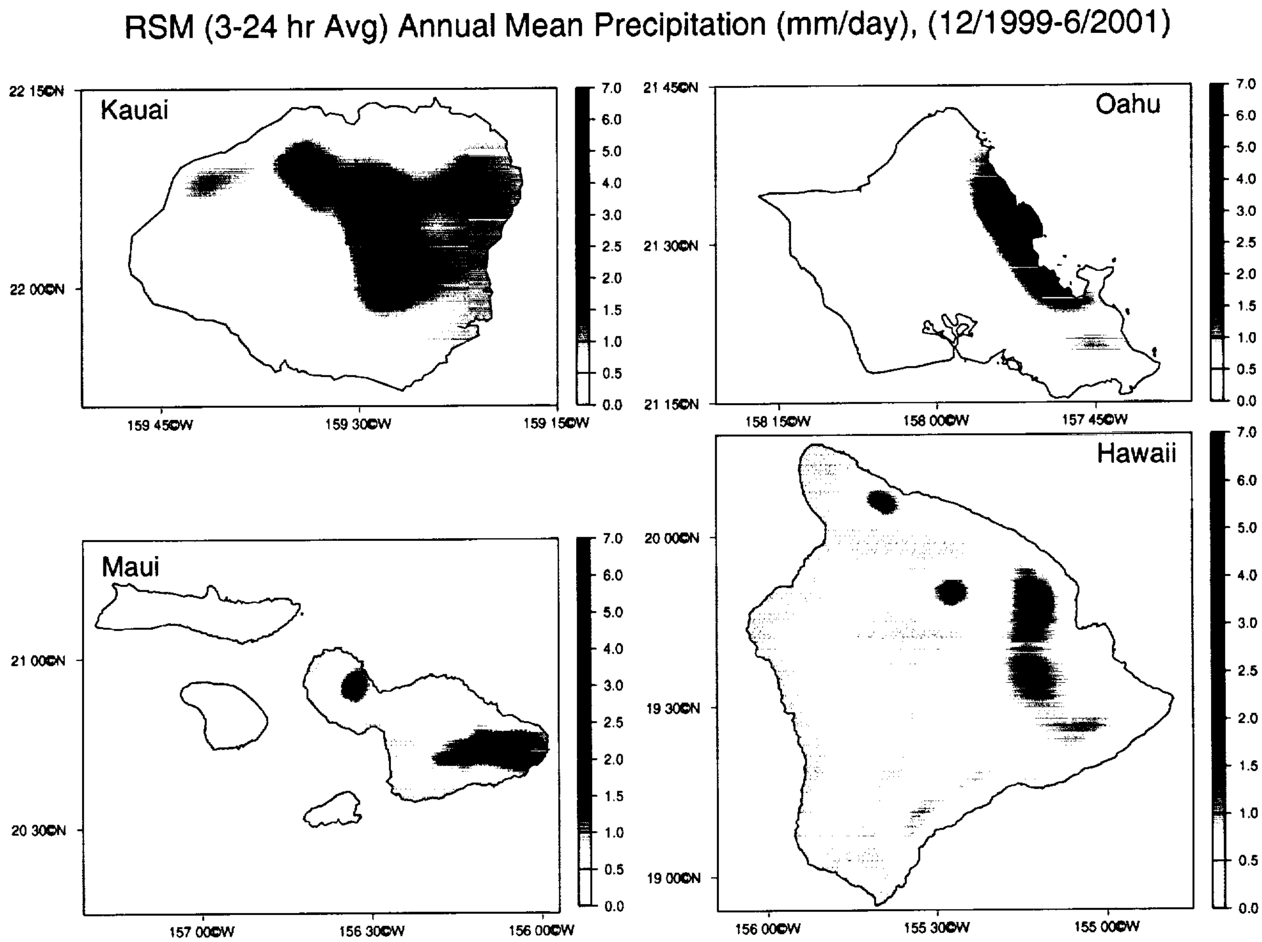

Fig. 3 Annual mean precipitation (mm/day).

Fig. 3 shows the average precipitation in the model. During this particular evaluation period the precipitation was fairly minimal, with the greatest amounts occurring in central Kauai. Relatively large amounts occur on the windward sides of all islands, where the orographic uplift provides sufficient cooling for condensation to occur.

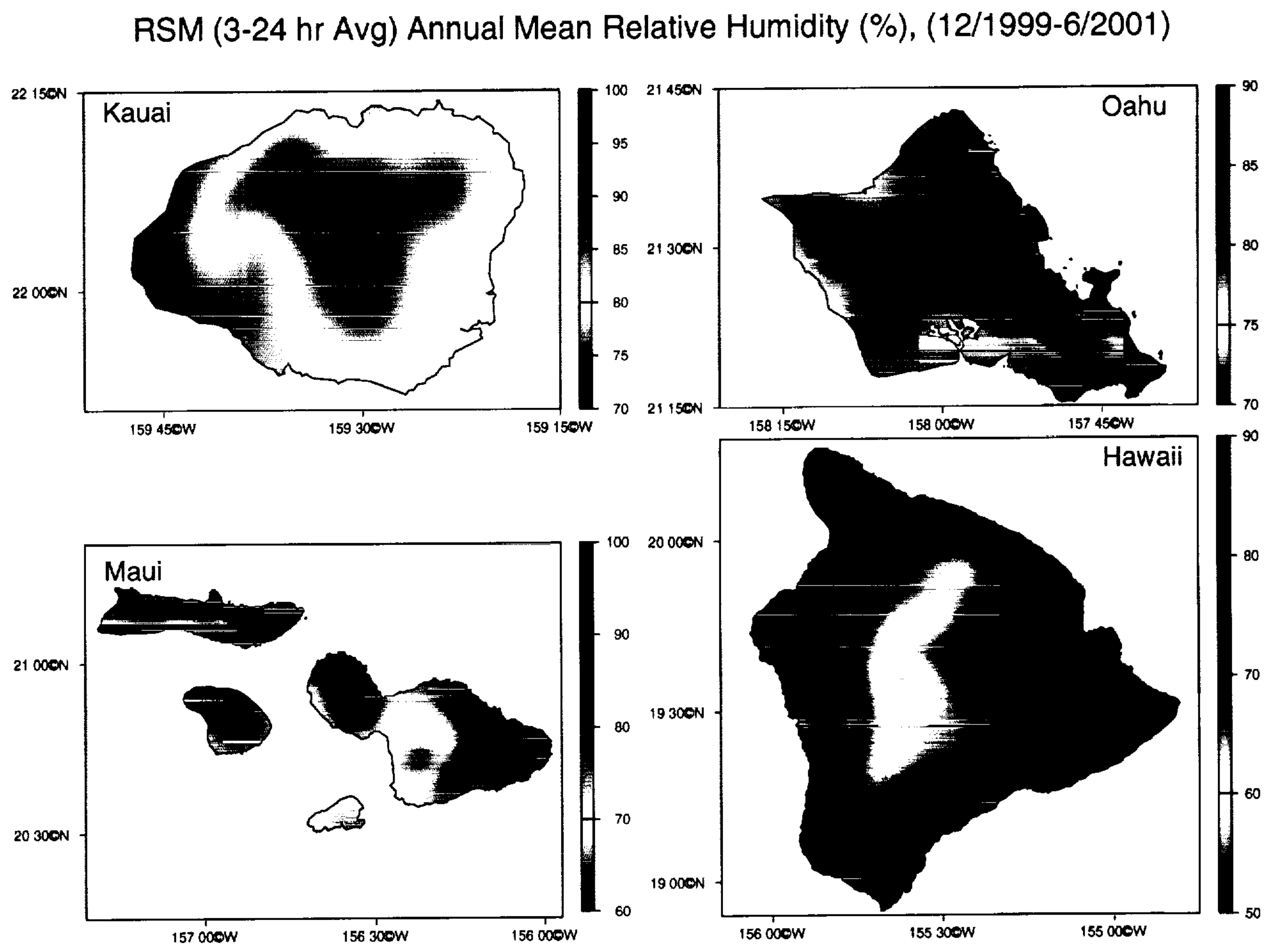

Fig. 4 Average relative humidity.

Fig. 4 shows the average relative humidity for the islands. Note that the relative humidity is greatest near the peaks of the mountains, except for the island of Hawaii, which has the greatest values in the coastal regions. Except for the peaks of Hawaii, the relative humidity distribution is, in many respects, the inverse of the temperature distribution.

RSM (3-24 hr Avg) Annual Mean Wind Speed (m/s), (12/1999-6/2001)

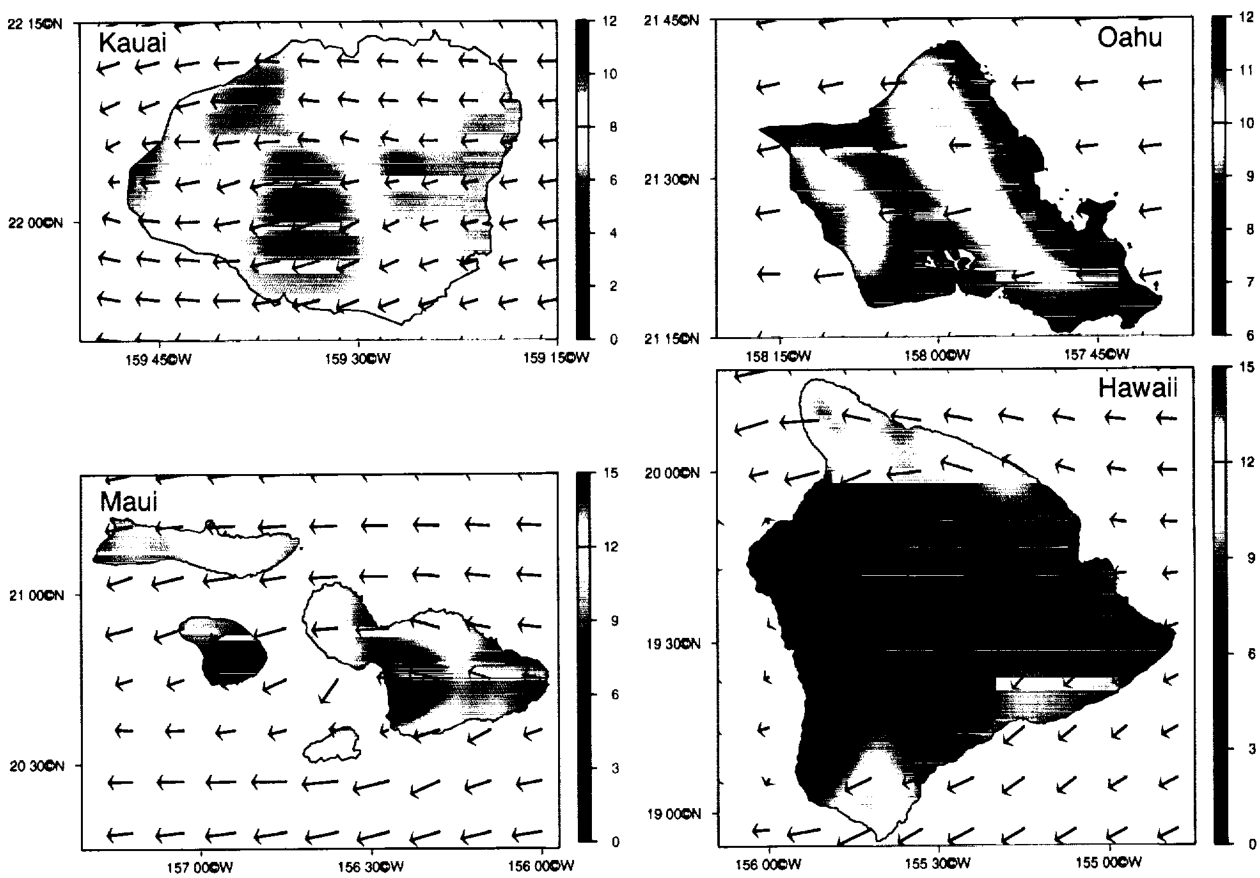

Fig. 5 Annual mean wind speed (m/s) and direction.

Fig. 5 shows the average wind speed and direction for the islands. For the most part easterly trade winds occur over the islands with perhaps the tallest island, Hawaii, having the greatest impact on the winds. It should also be noted that for the most part the weakest winds are on the windward side where rising motion occurs and stronger winds are found just to the westward lee of the mountain peaks. However, regions of return flow near the Kihei region of Maui and the kona coast of Hawaii are also regions of weak wind.

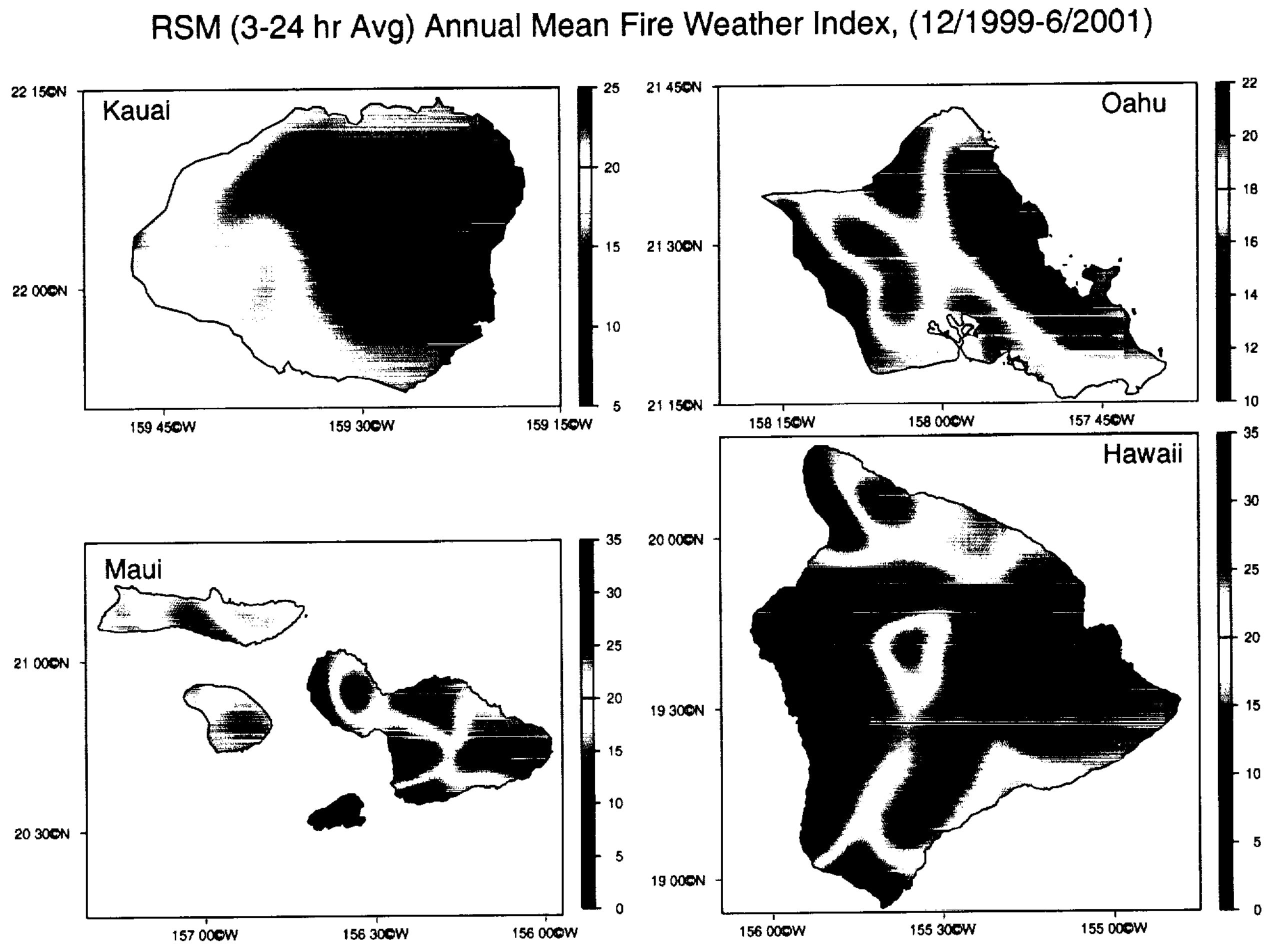

Fig. 6 Annual mean fireweather index.

Fig. 6 shows the average fireweather index, which represents an appropriate combination of windspeed and humidity. For example the lowest values occur over the low wind speed and high humidity areas. Higher values occur where the wind speed is higher and the humidity is lower. It should be noted that this fireweather index does not take into account characteristics of the vegetation, which are better described by the fire danger indices described elsewhere. However, preliminary comparisons do show the broad similarity of the fire weather index to the fire danger indices, which somewhat justifies the use of this simple index.

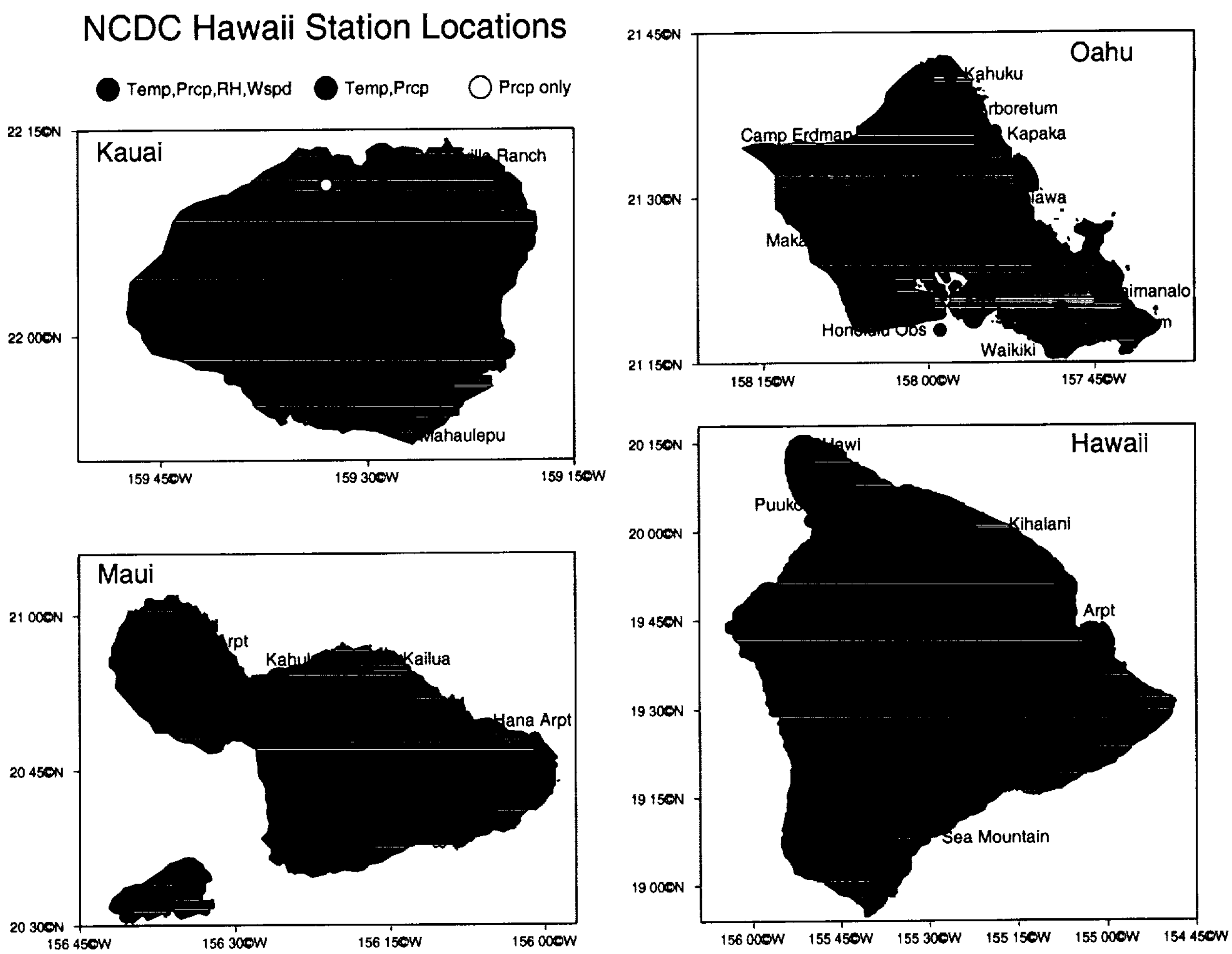

Fig. 7 Observation stations used for the current evaluations of RSM/MSM forecast skill.

In order to evaluate these values, we need to compare them to individual observations. Available observations from NCDC are shown above in **Fig. 7**. As may be seen, the majority of the NCDC observations are temperature and precipitation. Only 4 stations (at the island airports) also measure relative humidity and wind speed. Given the scarcity of stations, we then decided to simply average all of the stations together and not try to analyze whether certain stations are better forecast than others for now.

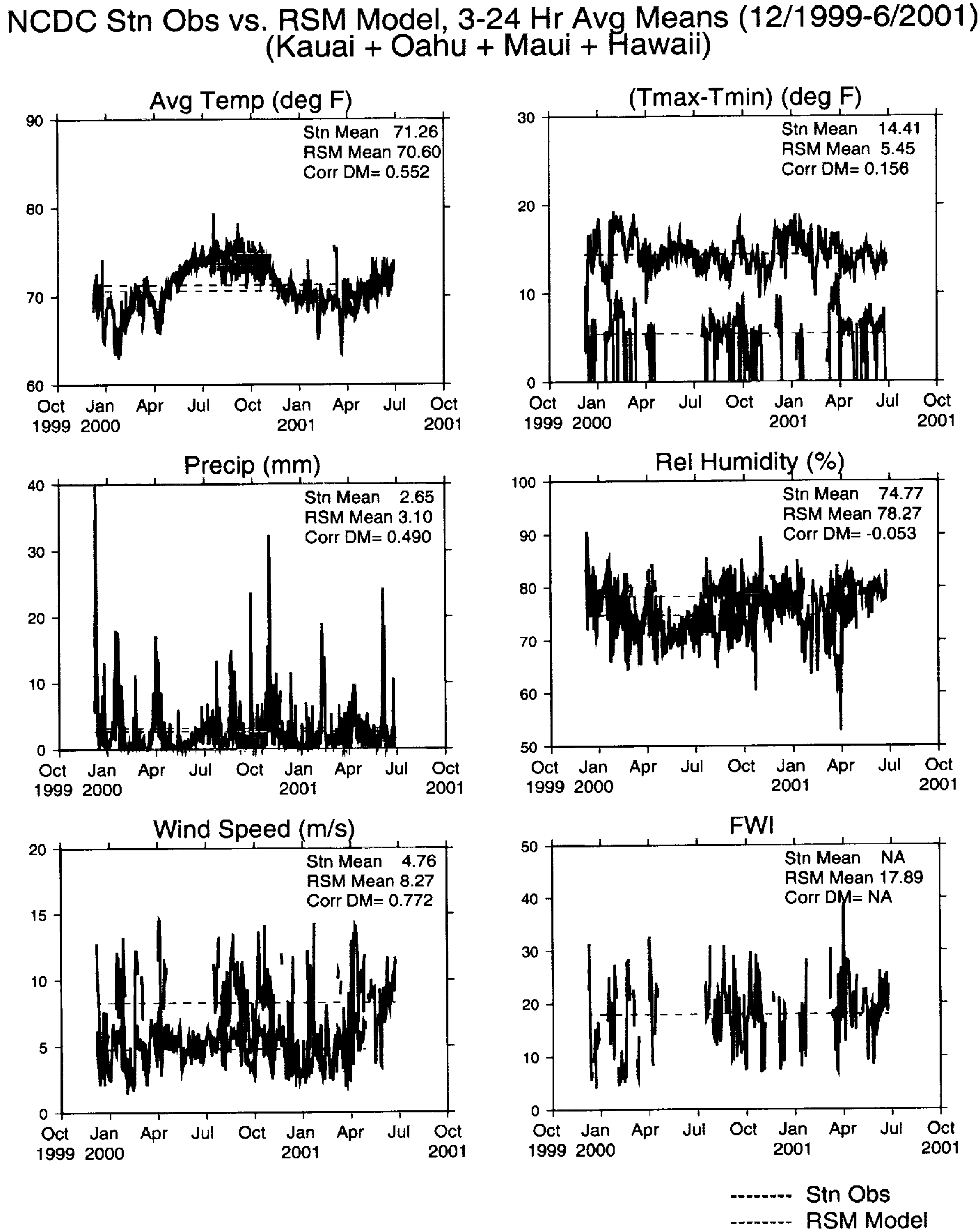

Fig. 8 Max, min temperature, precipitation, relative humidity, and wind speed comparisons for the all island averages.

The model values have some differences with the observations as shown in **Fig. 8**. Note the reduced maximum temperature and the increased minimum temperature, indicating that the model at these observation points, have a reduced diurnal cycle. As shown in Table 1, this diurnal cycle increases in the second 24 hour forecast, which indicates that part of the bias comes from the initial global conditions. The precipitation shows a respectable forecast mean as does the relative humidity. However, the model surface wind speed is a bit too high, which may bias the fire weather index.

Forecast correlations were calculated by first removing the seasonal cycle since we did not want to bias the skill with any strong seasonal variations. For example, the highest correlations were the forecast temperature field (.552) and if the seasonal cycle had been included the correlations would have been closer to .86. Precipitation forecasts are also well correlated with observations (.490), which is somewhat surprising but given the strong orographic rainfall, Hawaii may be an easier place to forecast precipitation than most. The model does not seem to have forecast skill (at least beyond depicting the climatology) for relative humidity variations, which is probably due to the small relative humidity variations there. However, despite the high wind speed bias, the model does seem to have the capability to forecast wind speed variations, and the fire weather index may therefore provide at least partially useful FWI forecasts. A number of other useful applications (VOG, air pollution transport) are already utilizing our experimental output and there are a number of other applications that could use of our routine forecast/analyses.

Table 1 summarizes the results as well as limited comparisons for the 48 hour forecasts. Note that the highest skills occur during the first 24 hour forecasts but that there is still some useful skill for even the 48 hour forecasts.

	OBS	RSM	Corr	Obs	RSM 24-hr	RSM 48-hr	Corr 24-hr	Corr 48-hr
Temp (F)	71.26	70.60	0.552	70.39	70.00	69.01	0.599	0.356
Tmax-Tmin	14.41	5.45	0.156	14.51	6.19	6.27	0.201	0.110
Precip(mm)	2.65	3.10	0.490	2.33	2.78	4.02	0.613	0.546
RH (%)	74.77	78.27	-0.053	74.96	77.02	75.83	-0.154	-0.225
WS (m/s)	4.76	8.27	0.772	4.61	8.61	9.51	0.805	0.663
FWI	NA	17.89	NA	NA	19.78	21.75	NA	NA

Table 1. RSM Fcsts vs. NCDC Station Obs. The first 3 columns show the means and correlations for the first 24 hour forecasts for the period of record (12/1999-6/2001). The next 5 columns show similar correlations but for the shorter period during which we had 48 hour forecasts (3/2001-6/2001). Note that NA indicates this quantity was not available.

To summarize, we now have a working model climatology for most of the RSM/MSM output and this climatology could be used to further distinguish between periods of above and below normal climate behavior, with some degree of confidence given that the daily forecast skill is significant for almost all forecast meteorological variables (even when the climatology is removed). However, we still need to develop an analysis of fire danger and drought indices in order to: (1) assess possible periods of relatively increased danger; (2) examine the relationships among all the firedanger and drought indexes; (3) compare our simplified fire weather index to these more comprehensive indices. Such work is still underway and is discussed briefly in sec. 3.2.

3.1.2 H igh Resolution MSM Case Study

The 1-km resolution is a continuation in the investigation of the characteristics of high-resolution modeling. It involved reconfiguring the MSM that covered the island to preserve topographic boundary conditions that had been used in the two-kilometer run. The change effectively reduced the time-step from 20 seconds to 5 seconds in the model and increased the time to complete the run to nearly 24 hours to complete a 24-hour forecast. The main benefit is that orographic features are better definition of small-scale features and possibly able to reproduce valley circulations and more realistic island interactions.

The model ran 48-hour simulations for four days in 2000 August on 8/13, 8/14, 8/15, and 8/16. The intent was to have a sufficiently long period to analyze each day and to avoid model spin-up effects. Each run overlaps one another allowing a comparative analysis between runs based on different global forecasts. The August 13 model run served as a test run for the model configuration and not part of the analysis.

Two regions on O`ahu used for analysis in this section are Makua Valley and the Schofield Plain. One reason for choosing these regions was the opportunity to take part in the US Army burn experiment where controlled burns were conducted for study of brush fire behavior. Another, mentioned earlier, was the availability of remote area weather system (RAWS) stations. These automated sites provide hourly observational data used by the military. Six stations were used, three in Makua and three in Schofield. This section here is to have a preliminary examination of the 1-km model output and compare them to observations. Basically, the objective is simply to discuss the differences seen.

Makua Valley

Makua Valley is located on the leeward coast on the northwest portion of O`ahu. The two-kilometer run is unable to define the valley and as such, not a viable representation. The one-kilometer grid spacing is more effective and allows the opportunity to study the model's simulation of the region. The analysis involves three sites corresponding to RAWS sites in Makua allowing the use of observational data for model validation. Further analysis of the observational data show a lack of observations on the valley floor with the site along the ridge providing the most regular data.

Temperature

The model temperature shows a regular diurnal cycle that has a range mean of 4.2° C. As expected, the warmest temperatures are associated with the Makua Range Control being nearest to sea level and the coolest with the Makua ridge site. The transition between night and day is not as dramatic as the observed as seen from the Makua ridge site (Fig. 1). The observed temperature peak exceeds the model peak by as much as 2.8°C for the ridge. Figure 2 shows the Makua Portable indicates a similar difference between observations and model indicating

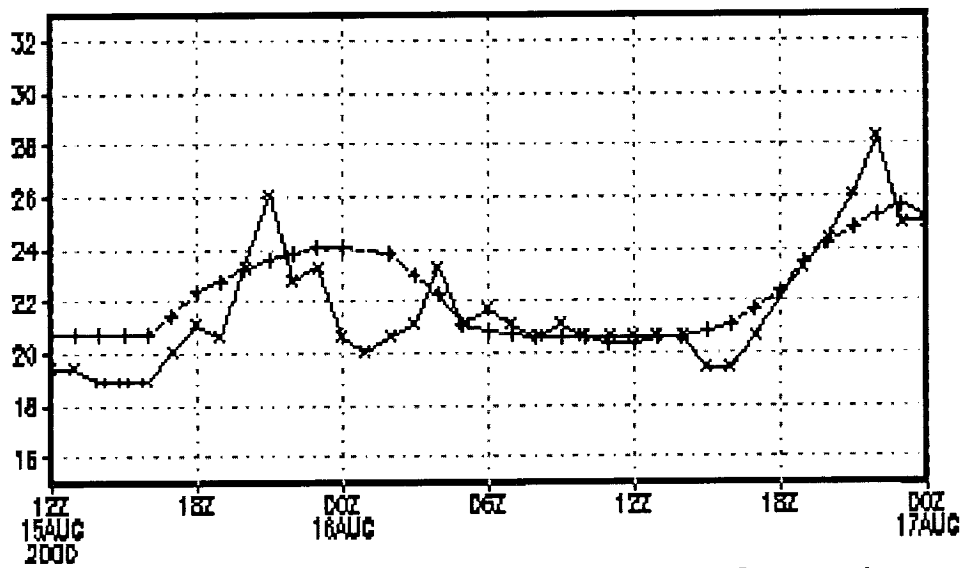

Fig. 1. 36–hour time series of model (+) and observed (x) Nakua Ridge temperatures (°C) for 2000 August 15 MSM run.

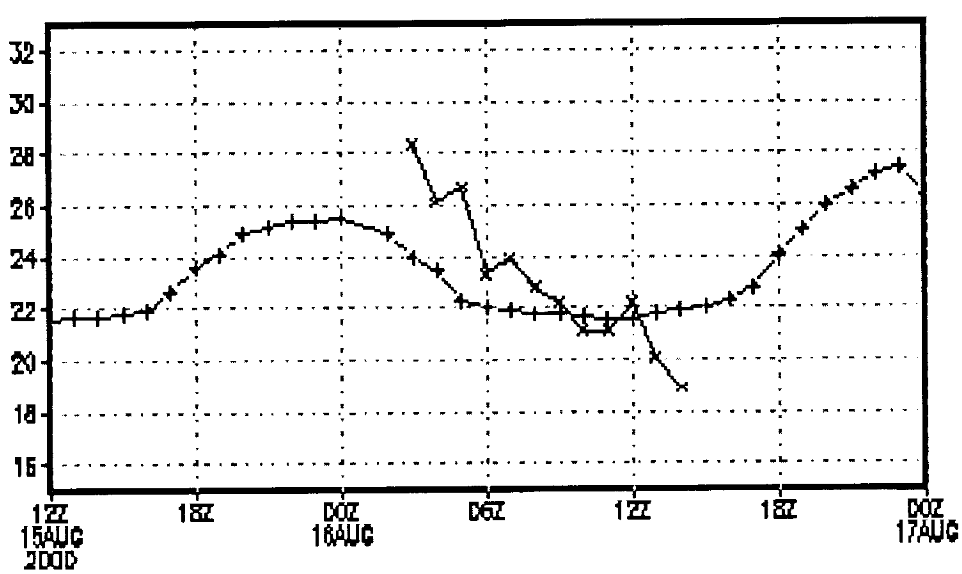

Fig. 2. 36–hour time series of model (+) and observed (x) Nakua Portable temperatures (°C) for 2000 August 15 MSM run.

an underperformance by the model. The overnight values are warmer though closer to observed values.

Short Wave Radiation

The assessment of incoming solar radiation shows the model values with regular pattern that rises upon sunrise (0700 HST), peaking in the early afternoon, and then goes to zero at dusk (2000 HST). This pattern is persistent for each run, implying nonexistent cloud cover. The Makua ridge observations follow the model transition at dawn and dusk. The daylight hours show no pattern but can be attributed to clouds due to orographic lifting over the Wai`anae mountains. Figure 3 illustrates the distinct pattern between model and observed values for the Makua ridge site.

10-Meter Winds

Wind analysis for Makua in general indicate strong trade winds with little variation in direction, which contrasts greatly with observations. The 2000 August 14 36-hour model streamline analysis, valid for 12Z on 15 August, shows the strong winds exceeding 10 m s^{-1} and no valley circulation present (Fig. 4). This finding is not surprising since such wind speed with have less interaction with topography. The streamline analysis shows winds to be strong for each model run. Any expected atmospheric interaction (increased wind speed, evidence of convergence, etc) with the valley does not show up. Makua portable model wind direction

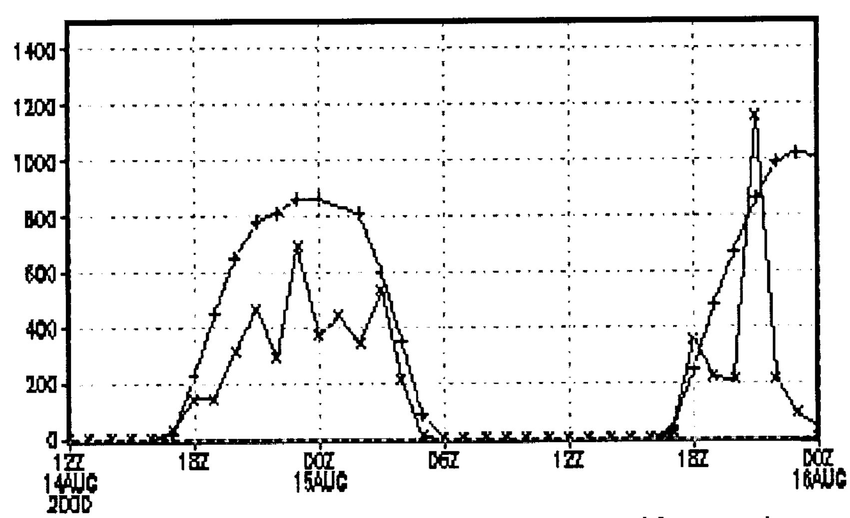

Fig. 3. 36–hour time series of model (+) and observed (x) Makua Ridge incoming short wave radiation (W m^{-2}) for 2000 August 14 MSM run.

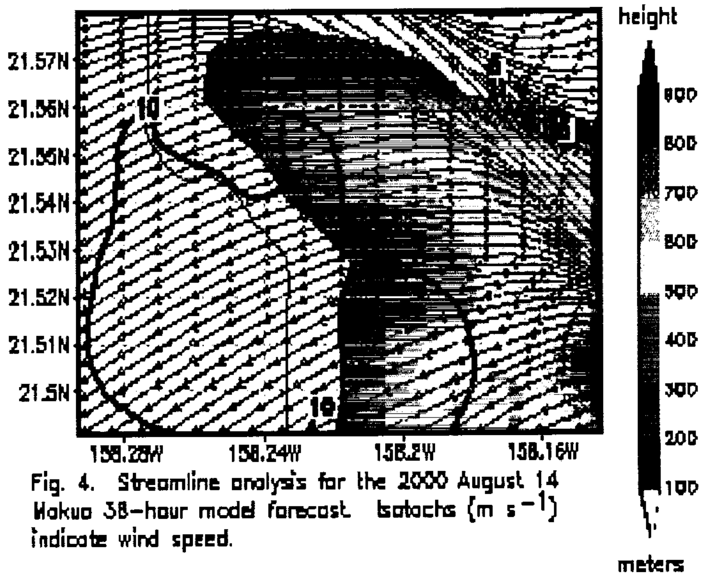

Fig. 4. Streamline analysis for the 2000 August 14 Makua 38-hour model forecast. Isotachs (m s^{-1}) indicate wind speed.

remained steady throughout the day. The observations, despite missing values, indicate a wind shift from nominally easterly to an onshore direction, a sea breeze signature. Makua Range also indicated a sea breeze. The model winds are persistently strong for each run with the observations showing lower values on a consistent basis Makua Ridge has a low frequency cycle in the model wind speed compared to the more variable observations (Fig. 5). Also evident is an increasing trend in the model where observed data shows fluctuations without any longer term change.

The conclusion here is that the lack of local interaction results from the 10-km Hawaiian Islands run predicting layer-scale strong trades. This renders the 2-km resolution predictions as having strong trade winds and hence, no local interactions.

Precipitation

Model and observed precipitation indicates values similar in magnitude as seen at the Makua ridge site for 8/14 and 8/15. The timing of the events has a delay between model and observed values by one hour later (8/14) to being several hours early (8/15). While timing of the forecasts is important, the more telling aspect is the magnitude comparison with a maximum difference less than 1.5 mm where observations are available. The Makua Portable observations are sparse, but indicate model and observed values possessing similar magnitude of rainfall amounts.

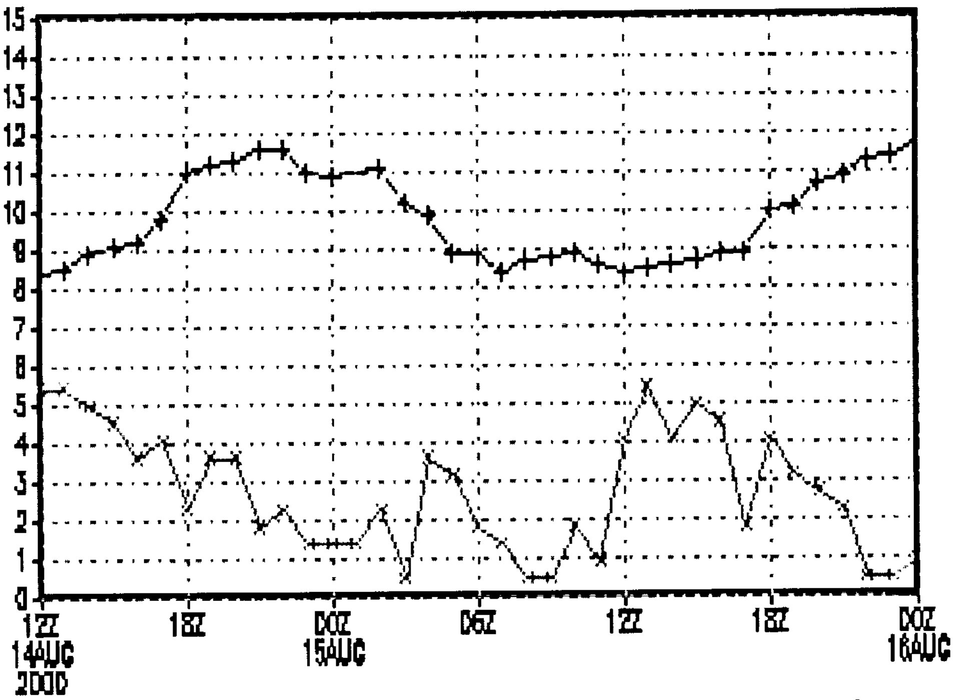

Fig. 5. 36–hour time series of model (+) and observed (x) Makua Ridge wind speeds (m s^{-1}) for 2000 August 14 MSM run.

Schofield Plains

The Schofield Plain is situated on the central plain at elevation (> 200 meters) separating the Ko`olau mountains and Wai`anae range. Unlike Makua Valley, precipitation may be greater since the rain shadow is of one mountain range instead of two. Additionally, the RAWS observations are mostly available for validation. Available RAWS sites are Schofield Barracks, Schofield Portable, and Schofield East. The first two are located near the eastern slopes of the Wai`anae range with the third situated on the 'East Range'. All three are on the Schofield Barracks Military Reservation.

Temperature

The August 14 temperature time-series for the Schofield Barracks site is displayed (Fig. 6). Again, the model values show a regular diurnal with the difference in extremes to be less than that shown for the observed values. The model values have a smaller range of extremes with a mean of 4.6° C, this observed range of extremes are nearly double at 9.3° C. The model maximum temperatures are cooler than observed by 3.9° C, minimum temperatures are warmer by 1.0° C. The comparison is similar to the time-series for Makua Valley where it underestimates the maxima and overestimates the minima as well.

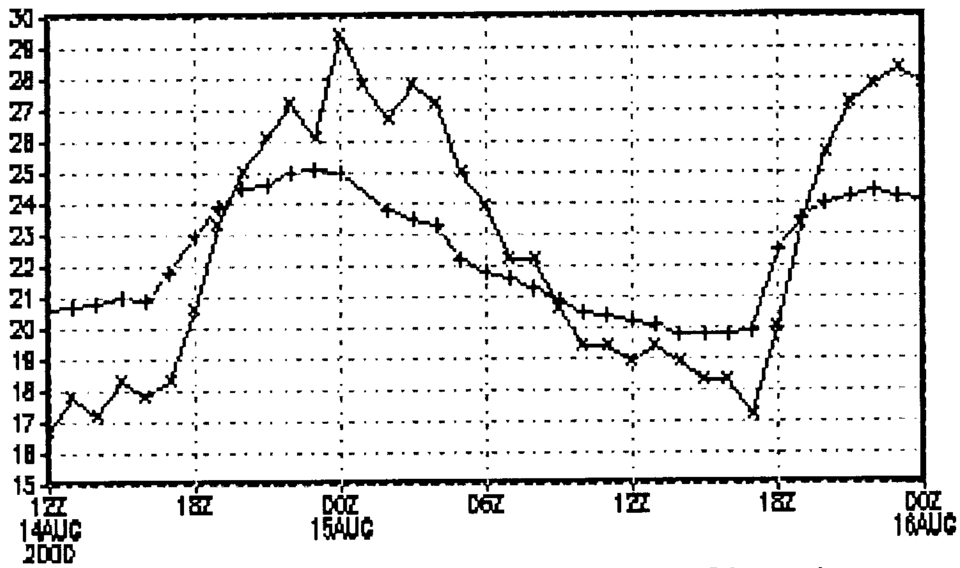

Fig 8. 36-hour time series of model (+) and observed (x) Schofield Barracks temperatures (°C) for 2000 August 14 MSM run.

Short Wave Radiation

Incoming solar radiation for August 16 shows a diurnal change from dawn to dusk. The general symmetry of observed values with modeled shows a lack of attenuation of the short wave radiation, indicating sufficiently clear skies, allowing a direct comparison of incident solar radiation. The Schofield Barracks site shows an underestimation in the afternoon (Fig. 7). Schofield East values present an overestimation. The observed values decline earlier and more rapidly than the modeled values (Fig. 8). The short wave radiation trend for the Schofield sites may be the sun setting behind the Wai`anae mountains cutting off direct incident radiation from the sensors. This also explains the observed lag at the Ko`olau range at dawn. Mountainside cloudiness also contributes toward masking the incident radiation when at extreme angles.

10-Meter Winds

Figure 9 shows the August 15 MSM run with the wind direction time series for Schofield Barracks. The obvious difference is the evidence of a wind shift in the model winds. The interval between the 37-hour (12Z, Aug. 16) and the 42-hour (18Z, Aug. 16) periods show a nearly 180-degree shift. The transitions are sharp in nature similar to the observations but showing a longer reversal period. The August 16 MSM run shows a similar pattern in wind direction and apparently closer to actual observations (Fig. 10). The latter half shows the model winds maintaining a northeasterly direction while the observed winds become light and variable.

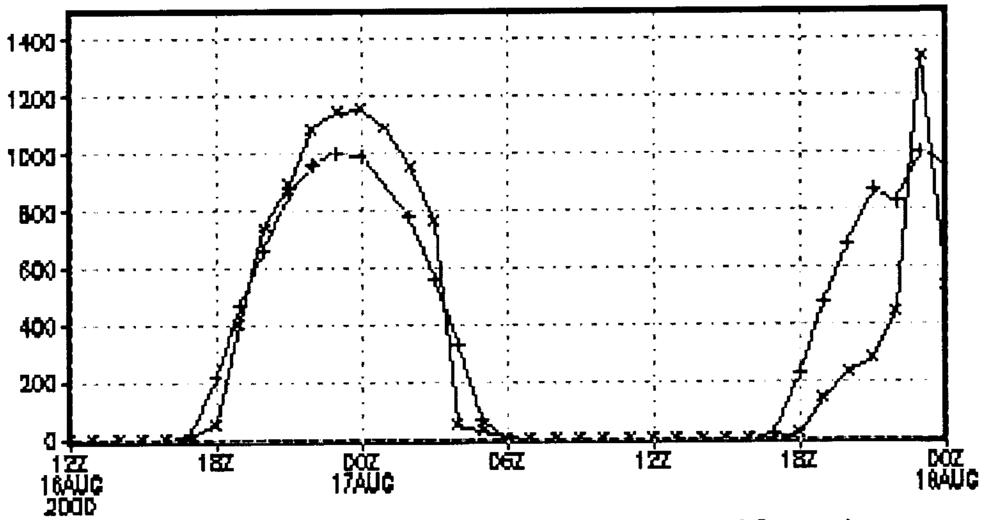

Fig. 7. 36–hour time series of model (+) and observed (x) Schofield Barracks short wave radiation (W m^{-2}) for 2000 August 16 MSM run.

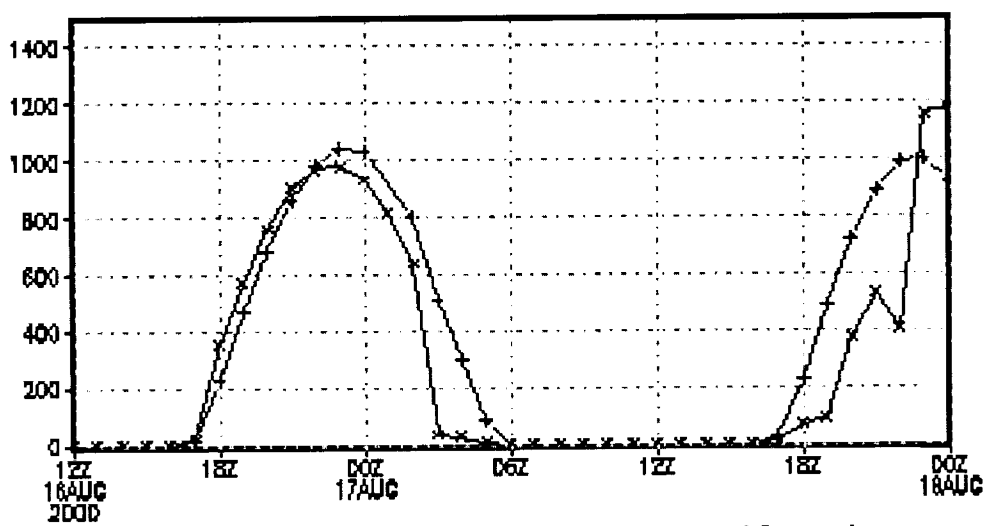

Fig. 8. 36–hour time series of model (+) and observed (x) Schofield East short wave radiation (W m^{-2}) for 2000 August 16 MSM run.

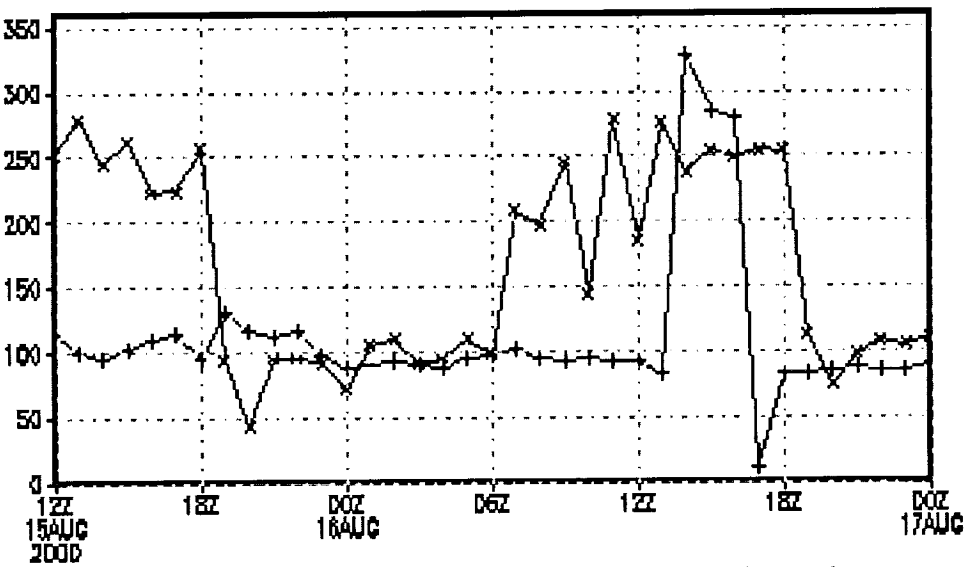

Fig. 9. 36–hour time series of model (+) and observed (x) Schofield Barracks azimuthal wind direction (°) for 2000 August 15 MSM run.

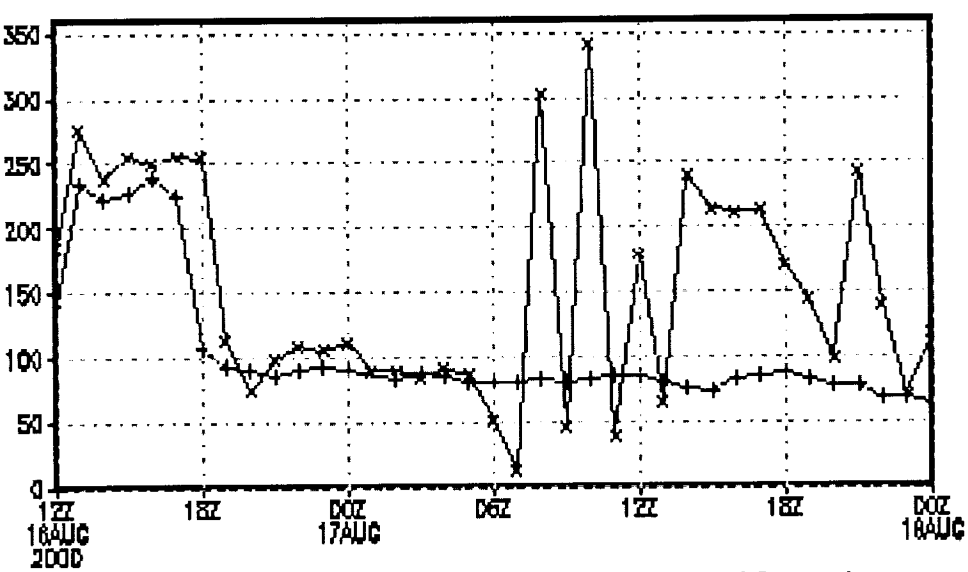

Fig. 10. 36–hour time series of model (+) and observed (x) Schofield Barracks azimuthal wind direction (°) for 2000 August 16 MSM run.

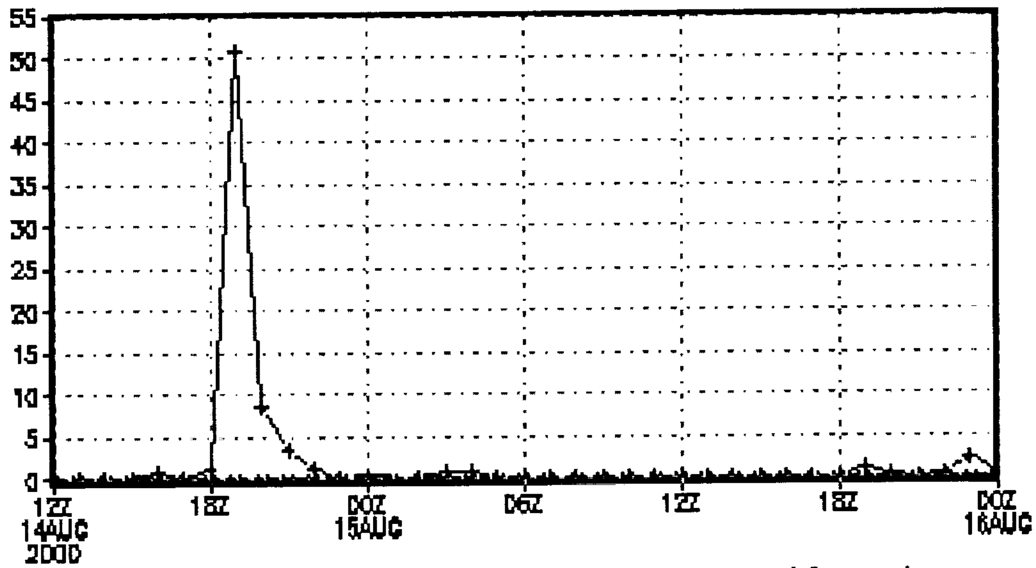

Fig. 11. 38–hour time series of model (+) and observed (x) Schofield Barracks precipitation (mm) for 2000 August 14 MSM run.

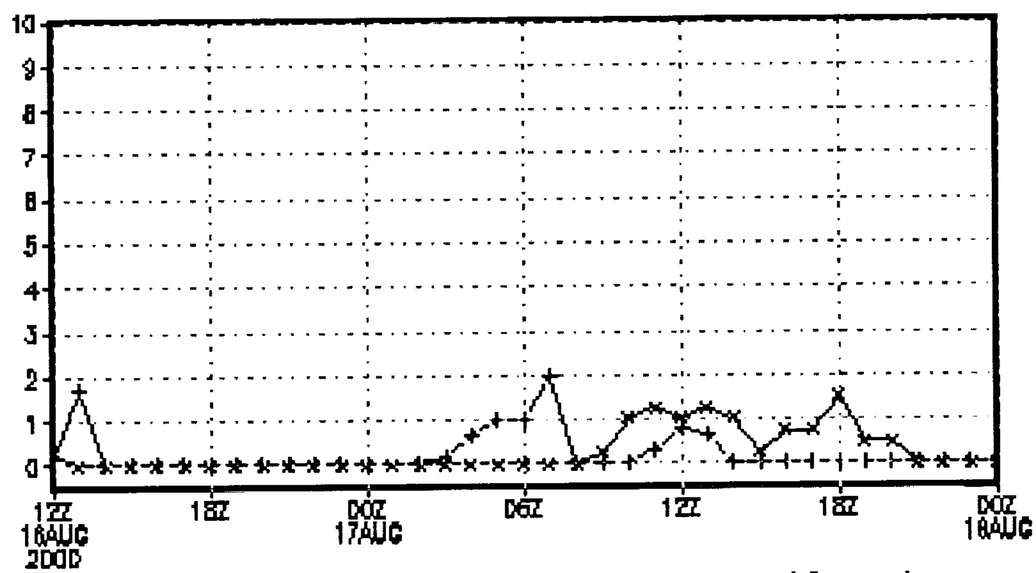

Fig. 12. 38–hour time series of model (+) and observed (x) Schofield East precipitation (mm) for 2000 August 16 MSM run.

Precipitation
The August 14 Schofield Barracks precipitation based on the August 14 MSM Run is shown (Fig. 11). The main difference is that the model shows the large precipitation values in excess of 10 millimeters by the 19-hour forecast (19Z, Aug. 14). The observations show no rain through the period. The Schofield Portable shows similar results. Unlike the Makua sites, the model fails to produce any semblance of realistic values. Schofield East, which is essentially isolated from the other two, shows little precipitation. The model does not appear to be consistent in predicting precipitation events since the August 16 MSM run shows rainfall event predicted for Schofield East with comparable magnitudes (Fig. 12). Again, the onset is off by several hours between the model and observations. Nominally, Schofield Barracks indicates no events predicted; that concurs with observations for the same period.

Discussion
The model runs shows apparent inconsistency of predicting events on a daily basis. The runs are on a 1-km grid that is nested in a 10-km grid providing input that is ultimately dependent on global data. The assumption is that it provides the initial analysis and serves as a forcing function for the running of the higher resolution simulations. The study of the three days shows various degrees of skill, but the fact remains that each day had different global data involved. Again, what is seen is that mixed results are present. The 10-m winds are consistently strong for each model run for the entire island. The expectation is that the change of grid resolution and increased resolution of topography would induce greater interaction at smaller scales such as those associated with valley circulations. The Makua Valley streamline analysis fails to discern any indicators that topography has significant impact on the flow into the valley. Conversely, the Schofield sites indicate the prediction of down slope flow from Mount Ka`ala that is confirmed by observations. The nature of this event is in evidence for two consecutive days showing the model's ability to simulate such events.

The 1-km MSM runs show stronger than observed wind events, overestimation of daily highs, and nominally similar precipitation magnitude but a difference in the onset. The evidence shows that the model has some drawbacks with the treatment of high-resolution simulations. The assessment of the results presented suggests that the MSM needs some additional improvements and may be correctable, but that is outside the scope of this text.

Conclusions
The 1-km output shows biases seen in the 2-km output remain present. The biases are likely to be exacerbated by the strength of the winds. The model winds are stronger than observed, pointing to the effects of large-scale flow. The need of local observations into the model is needed as forecasts overestimate actual values by a large amount.

3.2 Hawaii Fire Danger Evaluation

The National Fire Danger Rating System is now a national system whose use has been mandated to the U.S. Forest Service, and is also being used by other federal wildland management agencies (Bureau of Land Management, Bureau of Indian Affairs, U.S. Fish and Wildlife Service) and numerous state land management agencies. For the continental U.S., weather data is taken daily at over 1200 fire weather stations scattered across the country. These data are managed by the Weather Information Management System (WIMS) which contains the software used to process fuels, weather and topography data into fire danger indexes. The WIMS also archives daily weather observations as well as fire occurrence data for future reference and analysis. Processing occurs on the IBM mainframe computer at the USDA National Information Technology Center in Kansas City. The system is accessible 24 hours a day. Maps of the various fire danger indexes and other outputs are available to users at the Wildland Fire Assessment System (WFAS) website: http://www.fs.fed.us/land/wfas/welcome.html System oversight is through the National Advisory Group on Fire Danger Rating, with representatives from both state and federal wildland management agencies.

The NFDRS has several uses:

1) Determination of daily industrial fire precaution level. Relationships were established between fire danger indexes and final fire size, then used to calculate a graduated scale of restrictions used by most agencies in the Pacific Northwest to regulate industrial operations, resulting in a significant reduction in industrial related fires.

2) Determination of regional preparedness levels. Fire coordination centers must assess their readiness level on a daily basis. Their decisions may include pre-positioning resources, requiring off-duty personnel to report or ordering contingency resources from outside the area.

3) Support of severity requests. Most agencies have some process whereby local units can request additional funding to supplement their basic presuppression organization funds. This usually requires supporting data to show that their current conditions are more severe than those anticipated during their planning efforts. Often, current values of selected NFDRS indexes are compared with historic worst case and normal values for the corresponding dates to support funding requests.

4) Facilitation of Briefings. Inadequate briefings of firefighters unfamiliar with the local area, as to expected conditions, has resulted in loss of life on several wildfires. In 1997, the NAGFDR developed a Fire Danger Rating Pocket Card for Firefighter Safety as a tool to aid in these briefings. Among other things, this card contains information about levels of NFDRS indexes associated with recent large fires that occurred in the local area; thresholds of critical fire behavior based on local experience, and local fire danger interpretations.

5) Preplanned dispatch. Many units preplan their actions in response to reported incidents by comparison of historic fire size with the various fire danger indexes. A graduated response can be developed based on local experience in using the NFDRS outputs.

6) Guidance of public use restrictions. Analysis of local conditions associated with human caused fire occurrence can help determine when to initiate public use restrictions. By establishing a relationship between human caused fire starts and the current values and trends of fire danger indexes, one can target and time the implementation of specific public use restrictions.

Because the HFDRS is newly established for Hawaii, it will be necessary to build an archival of fire weather and fire danger index data so relationships between index values and fire activity can be determined. These relationships are required for all of the previously mentioned uses of fire danger rating. Because the HFDRS outputs fire danger index maps directly, rather than index values for specific weather stations as is done on the mainland, currently available analysis tools may be inadequate. Further improvements on the resolution of the weather data would be useful in that this would make better use of the 1km resolution fuel model map.

4. Summary and Future Efforts

Since the beginning of the PDC project, near real time and routine forecast data have been made available to PDC even while we worked to enhance this information. Our initial products, which came from 24 hours of the MSM were available in near real time but timeliness and consistency of output were major issues for running high resolution models on older computers with a number of weak operational links. We have since extended the MSM forecasts to 48 hours, with the initial forecasts now available by 7am every day by taking advantage of the latest open mp processors at MHPCC and letting the output processing be done in parallel with the model execution as well as through the addition of many redundant and fault tolerant scripts and accessing the input data directly from NCEP. Comparable MM5 forecasts are made out to 30 hours 12 hours later. These mesoscale forecasts now provide higher resolution forecasts at greater time horizons than are available from the National Weather Service. However, it should be remembered that the National Weather Service is in charge of issuing official forecasts and PDC will need to work with them in the future to make them aware of the unique possibilities of the current operational system for not only increasing the accuracy of the weather service forecasts but also for having access to the additional digital data available for driving other application models. High resolution analyses of various events could also be developed from the routinely archived data at MHPCC or Scripps.

Our initial simplified fire danger product, the Fire Weather Index (FWI), which is based only upon meteorological conditions was augmented for PDC by development of a new Hawaii Fire Danger Rating System, which is based on the National Fire Danger Rating System (NFDRS) that has been used over the continental United States since 1978. In addition to fire danger indices, a drought index is also produced as part of the fire danger rating. There are three basic inputs to computing fire danger rating: weather, topography and fuels. Because fire danger is a cumulative phenomenon, weather is the driver in terms of producing seasonal changes in fire danger estimates. Topography is used to reflect the fact that fire burns faster upslope than on flat ground. Vegetation is deemed to be fuel for fire danger rating purposes. Twenty NFDRS fuel models represent the vegetation types across the U.S., defining fuel characteristics such as depth, load by live and dead classes, heat content, fuel particle size, etc. These basic inputs are converted into various fire danger indexes by processing them through a modified version of the fire spread model It should be noted that the Hawaii Fire Danger Rating System (HFDRS) differs from the National Fire Danger Rating System in that the HFDRS calculations are done using gridded fuels, weather and topography data instead of station data. The fuels data for the HFDRS is defined at 1km spatial resolution, while the weather data is at 2, 3, or 4 km resolution, replicated to 1km resolution. The higher resolution fuels data permits display of more fire danger variability through the assumption that the actual weather parameter values are reasonably constant within a 4, 9, or 16 square km area.

A number of preliminary evaluations of HWCMO products, climatological as well as a high resolution case study with the MSM indicated that the current system provides significant and useful forecasts. There are still problems that users must be aware of, such as a damped diurnal cycle and too high wind speeds but with proper knowledge of the forecast biases, users should be able to use the forecasts for a large number of applications. For example, besides using the output for fire danger and drought predictions, output from the 48 hour MSM forecasts are now being used to drive a volcanic aerosol transport (vog) model, which was another PDC supported research project. Other applications, requiring routine high resolution forecasts/analysis could also be supported.

Our major concern at this point is whether we can keep this HWCMO/PDC effort going past the end of the contract. We would like to continue to be part of a subsequent PDC team if at all possible. We believe we can provide, on a regular basis, all the meteorological data products that PDC needs for high-resolution analysis of meteorological disasters for the Hawaiian islands. We also can provide, on a regular basis, timely accurate forecasts for PDC applications, such as fire danger, drought, and vog.

Also, given that the current forecasting system has recently been extended past the initial 24 hour forecasts to 48 hour MSM forecasts and 30 hour MM5 forecasts and given that the previous evaluations were done for the first 24 hours, we still need to further understand what kind of loss of skill occurs at more extended time ranges. We also need to go beyond the initial evaluations to better explore various features of the current forecast system including boundary layer and sea breeze evolutions, precipitation distributions, comparison of fire danger predictions with fire occurrences, etc.. We also need to compare the MSM with the MM5 to determine if there is a clear advantage to one modeling system or whether both should or could be used depending upon the situation.

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Appendix I. HWCMO System

The RSM and MM5 codes are run every day by a cron job on MHPCC s IBM SP Nighthawk, *Tempest*, and controlled by a series of scripts that handle the downloading of data, preprocessing, job submission, image creation, and archiving of forecast output to mass storage. Below, we describe the daily operations in more detail. Also included is a cost analysis of running both models in parallel on *Tempest*. Finally, it should be noted that we have data from the RSM model stored since March 1998 and the MM5 model since March 2001, which could be used for further evaluation. (see http://www.mhpcc.edu/projects/wswx/catalog.html).

RSM Daily Operations:

1. Global forecast data is downloaded directly from NCEP at 6 pm HST.
2. The All Island (10 km) run is submitted to MHPCC's IBM SP Nighthawk system to be run in parallel on 4 processors.
3. After 6 simulation hours have passed, the all island web page is updated and this information is passed down to the nested county domains. Now the individual county runs (Hawaii county at 4 km, Maui at 3km, Oahu and Kauai at 2km) are submitted to MHPCC's IBM SP Nighthawk system to also be run in parallel on 4 processors each.
4. After each run is completed, the output data of the model at 6-hour increments is converted into images and posted to the Ohana web page at http://www.mhpcc.edu/projects/wswx.
5. When all runs are completed the output data (every 3h up to 48 hours) is kept in a separate directory for that day and held there for 5 days before it is archived.
6. After 5 days, all the data is packaged into a single file and compressed. It is then sent to MHPCC's mass storage system, HPSS. When the data is packaged and sent to HPSS it is also recorded to a web page. This record tells how many simulations hours were completed for the all island run as well as the individual county runs.

MM5 Daily Operations:

1. Global forecast data is downloaded directly from NCEP at 11 pm HST.
2. Preprocessing is done to prepare the NCEP data for use by the MM5 model.
3. MM5 runs in parallel on MHPCC's IBM SP Nighthawk system using either 16 or 32 processors depending on time requirements. Currently the model is run for 30 simulation hours. The 2-way nested domains are as follows: the 4 Hawaii counties are run at a 3 km resolution and are nested by a 9 km Hawaii state domain; the 9 km state domain is nested by the large 27 km pacific domain.
4. After the run is completed, data is converted into the appropriate format for image creation by the RIP program. This operation is done in parallel on the interactive nodes on MHPCC's IBM SP Nighthawk system (running about 6 times faster than sequentially (45 minutes to less than 8 minutes). GIF images are created at 1-hour increments and posted to the web page http://www.mhpcc.edu/projects/wswx/mm5. From these images animated GIF files are created to show a movie loop of the selected field (Fields include temperature, wind speed and direction, low-medium-high clouds, relative humidity, and rainfall).
5. All relevant data is moved into a single dated directory (including the web page images). To conserve space only 6-hour increment data output from the MM5 run is saved. The

directory is then tarred up and compressed before it is moved out to MHPCC's mass storage system, HPSS.

Script control:
RSM uses a variety of scripts to complete the entire operation of running the simulation.

1. The script *sendcron.s* is initiated as a cron job daily on *Tempest.*
2. It calls the script *run_clean.pl.*
3. This script determines what needs to be archived and transfers the data from the local file system to MHPCC s mass storage system, *HPSS.*
4. After the data is successfully transferred (and only if successful), it removes the data from the local file system.
5. The catalog file of successful runs is then updated to include archived data sets.
6. It then calls the script *run_ftp.s.*
7. This script transfers the necessary data sets from *NCEP* to the local file system.
8. Finally the *AUTORUN.s* script is called.
9. This script starts the *run_ohana.s* script.
10. This prepares and submits the 10 km run to *Tempest.*
11. The *run_island.s* script is started for each of the 4 counties.
12. This script delays the submission of the island runs until the 3 hour data has been output from the 10 km run for initiation.
13. Finally the image processing routines are set to sleep until the data has been output from the model s runs.

MM5 uses a single PERL script (with subroutines) to complete the entire operation of running the simulation.

1. The subroutine (*ftp*) determines the latest data set to acquire based on the current date (although there are control structures in place if you wish to run the simulation for a historic date). Data is then transferred from NCEP to the local file system.
2. The subroutines (*pregrid*, *regrid,* and *interpf*) preprocess the data downloaded from NCEP.
3. When final preprocessing is completed, the subroutine *mm5* is executed. This submits the job to *Tempest.*
4. The image processing subroutine (*web_post*) then waits from the model to output its data. Once completed it then converts the output data in images and animations, which are posted to the web.
5. Finally data is packed into a single file and archived to MHPCC s mass storage system, HPSS.

Parallel image processing:
RSM:

The image processing has been removed from the batch jobs because:

1. The job may take a long time before it is started since it is waiting in a queue with other users
2. The previous script submitted the job waiting for data to be produced (was spending CPU hours while waiting)
3. The job runs on the interactive nodes (does not incur a charge to the HWCMO project)

4. The job starts immediately when data is produced (sits on a while loop until data is available at no cost)

MM5:

Parallel image processing is now implemented. Works in much the same way as the above (operates on interactive (no charge) nodes) but is parallelized over not only the domains but also over the fields. Serial image processing was 45 minutes, but the parallel processing now takes under 8 minutes.

Cost Analysis:

All the counties use the same number of grid points. However, the run times are not the same, because hen you decrease the grid spacing, you must also decrease your time step in order to maintain numerical stability. Thus it takes longer for Oahu and Kauai to run for the same simulation time at 2 km resolution as opposed to the shorter time for the 3 for Maui and 4 for Hawaii. Based on our detailed cost analysis below, our suggestion for continuing routine forecasts with the present RSM system at MHPCC would be to use 1 to 4 processors depending on the domain for the RSM because:

1. Runs start at 6 pm (well actually the ftp download but if we say they start at 7 pm). If we want the output data to be ready by 6 am the next day then we have 11 hours to play with to accomplish a 48-hour run (things would change if we wanted a 72 hour forecast).
2. Since the all island run completes in 10:20 when run sequentially we may want to run it as such but this means that it takes longer for the individual counties to start execution (still about 40 minutes) so if we say the county runs have to complete in 10 hours then we now have clear restrictions on the number of processors we need to accomplish this goal (well really clear if I had 2 processor benchmarks). Cleary none of the counties can be run sequentially based on the current sequential benchmarks. However, 4 processors may be too much. We may want to use just 1 processor for the all island run and 2 for the county runs. Our best guess (w/o benchmarks) is that the daily cost of these runs will be ~66-70 CPU hours. If Oahu and Kauai are not coming out fast enough then 4 processors may be needed for them increasing the cost to ~85 CPU hours.
3. The cost for a year of runs would be 25,550 - 31,025 CPU hours per year, if 4 processors were used for Oahu and Kauai. I.e. If we are charged $1.5 per CPU hour then the cost would be $38,325-$46,537.

If we want a 48-hour MM5 forecast, there are 2 possible costs that fit the time frame for the data to come out by 6 am.

1. If we use 32 processors, then the cost would be 192 CPU hours a day to be completed by midnight - 1 am. Which is a cost of 70,080 CPU hours a year (i.e. at $1.5/CPU hour, a real cost of $105,120).
2. If we use 16 processors (as we are now), then the cost would be about 160 CPU hours a day by 4:30 am, which is a cost of 58400 CPU hours (i.e. at $1.5/CPU hour, a real cost of $87,600).

RSM cost analysis:

Domain	Run Time (H:M)	Run Time (minutes)
Ohana	10:22	622
Hawaii	12:08	728
Maui	12:14	734
Oahu	16:14	974
Kauai	16:34	994

The single processor cost is the least but does not produce timely 48-hour forecasts.

Domain	Run Time (H:M)	Run Time (min)	Speedup	Cost (min. 4 proc.s)	Parallel Efficiency
Ohana	4:27	267	2.33	1068	0.58
Hawaii	4:12	252	2.88	1008	0.72
Maui	4:25	265	2.77	1060	0.69
Oahu	6:27	387	2.52	1548	0.63
Kauai	6:29	389	2.56	1556	0.64

The 4 processor version is a lot more efficient than the single processor case although the total cost in minutes = 6044; hours = 100.7 is more expensive

Domain	Run Time (H:M)	Run Time (min)	Speedup	Cost (min. 16 proc.s)	Parallel Efficiency
All island	3:51	231	2.69	3696	0.17
Hawaii	3:12	192	3.79	4672	0.24
Maui	3:50	230	3.19	3680	0.20
Oahu	5:23	323	3.02	5168	0.19
Kauai	5:35	335	2.97	5360	0.19

The 16-processor version produces solutions quicker but not very efficiently relative to the sequential version or even the 4-processor version. The total cost is 349.6 hours per forecast.

MM5 cost analysis:

Benchmarks for the MM5 start at 16 processors, as the job cannot be run with less (memory constraint). Note that the table below is for a 24 hour forecast for the all island run.

Processors	Time (sec.s)	Time (H:M)	Cost (hours, 16proc.s)	Speedup	Parallel Efficiency
16	17639	4:54	78.4	1.00	1.00
32	10462	2:54	93.0	1.69	0.85
64	7452	2:04	132.5	2.37	0.59
128	5203	1:27	185.0	3.39	0.42

32 processors seem to be a reasonable choice for the MM5. If we were to go to a 48-hour forecast it would simply double execution time and the entire forecast would be done in 6 hours. The runs are currently started at 12 AM so it is feasible to complete a 48-hour forecast by morning if 32 processors are used. If the runs are started at 6 pm (like RSM) then 16 processors may be a better alternative for keeping costs down.

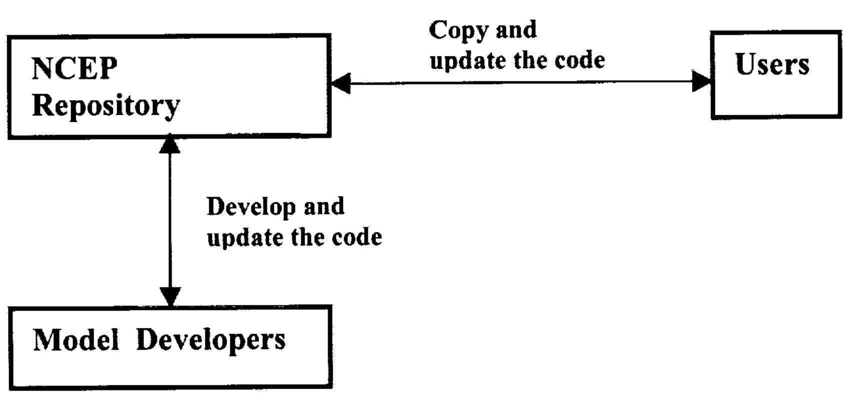
Appendix II. RSM/MSM/CVS User Mannual

(web site: http://ecpc.ucsd.edu/projects/RSM/)

1. Introduction

- A new version of the Regional Spectral Model (RSM/CVS) has also been developed to work within CPC/NCEP's GSM(Global Spectral Model)/CVS.
- The RSM/CVS system is managed by Concurrent Versions System (CVS) and controlled by configure files and Makefile system.
- The RSM/CVS system is an efficient, stable, state of the art atmospheric model designed for regional climate research.
- The RSM/CVS has the same structure as the GSM/CVS so that updates of model physics in the GSM/CVS system can be directly incorporated.
- The RSM/CVS currently works on on IBM-SP, Origin, and Dec-Alpha as January 2001 and is being tested on other platforms.
- The RSM/CVS has a parallel open-MP capabilty and the speedup is about 300% for 4 CPUs.
- Users can always be in touch with the latest version of the model through CVS system.

2. CVS system



2.1 CVS Installation and Simple Usage

(1) Installation

- First check whether you already have it on your system. Type cvs -h
- If you do not have it, get the source codes from the cvs home page, http://www.cvshome.org
  (see step-by-step installation guide below)
- Set environmental variable and add the *cvs_executable_directory* to your path.
  For example, add the following fragment to the .cshrc file:

```
set PATH=($path cvs_executable_directory)
setenv CVSROOT :pserver:anoncvs@lnx168.ncep.noaa.gov:/usr1/cvs-root/cpscvs
```

- Prior to CVS's installation, the computer system should meet the following requirements:

  C compiler installed.
  Fortran 90 compiler installed.
  Adequate disk space.

(2) Step-by-step installation guide

- Download cvs tar file:
  `ftp://ftp.cvshome.org/pub/cvs-1.10`
  Download the file cvs-1.10.tar.gz.

- Extract the cvs tar file:
  Type '`tar xvfz cvs-1.10.tar.gz`'.
  Or type '`gunzip cvs-1.10.tar.gz`' and '`tar xvf cvs-1.10.tar`'.

- Set up configuration:
  Change directroy to the cvs-1.10 directory.
  Type '`./configure --prefix=`*`directory_to_install_cvs`*'.

- Install CVS:
  Type '`make`'.
  Type '`make install`'.

(3) CVS commands

- login:
  Type cvs login (only once),
  then just return at the password prompt.
  Logged into the cvs server as a user name anoncvs .
  The access is read only.
- cvs co *modue_name*:
  Copies the directories and files registered under *module_name*.
- cvs diff *file_name*:
  Show the difference between your file and the file in the repository.
- cvs status *file_name*:
  Show the status of the *file_name*.
- cvs log *file_name*:
  Show the detailed log of the *file_name*.
- Refer to the web page for more commands.

2.2 Installation of RSM/CVS system

(`$DISK`: working directory)

- Install model library:
```
mkdir -p $DISK/libs
cd $DISK/libs
cvs co libs_rsm
```

- Install model source code:
```
mkdir -p $DISK/srcs
cd $DISK/srcs
cvs co src_rsm
```

- Install model run script:
```
mkdir -p $DISK/run
cd $DISK/run
cvs co scr_rsm
```

3. Model System Structure

The model is made of 3 main components:

- **Library (e.g., $DISK/libs):**
  - Contains model libraries, utilities, and constant fields (e.g., climatological and topography data).
  - Independent of model resolution but machine dependent.
  - Made only once.

- **Source code (e.g., $DISK/srcs):**
  - Contains model source code.
  - Generates model resolution dependent constants.
  - Defines model resolution and options.
  - Compiles the code and creates run executables.

- **Run scripts (e.g., $DISK/run):**
  - Runs the model and stores the model outputs.

RSM/CVS Tree Structure

```
|- libs/ -> |- con/
|           |- lib/
|           |- etc/
|
|- srcs/ ->|- src/
|           |- def/
|           |- opt/
|           |- bin/
|
|- run/ -> |- runscr/
|           |- [output]/
```

./src/-> albaer/ chgr/ cldtune/ cnvaer/ cnvalb/ cnvrt/ co2/ fcst/ include/ mpi/ mtn/ pgb/ sfc/ sgb/ share/ rbln/ rfcst/ rgsm/ rinpg/ rinpr/ rloc/ rmrgsfc/ rmtn/ rpgb/ rsfc/ rsgb/ rsml/

File name conventions

Source and library related files:

*.F : source with c-processor directives
*.f : source codes after c-processing
*.o: object codes
*.x: executables
*.a: libraries
*.h: includes
*.in: file template
No suffix: makefile, scripts, or constants
*.sh : script
. files are created after compilatio

Data and constant files:

*.Z : compressed
*.asc : ascii file
*.grib : grib format file
*.ieee : ieee binary (single precision) file

Source code naming and format:

One subroutine per file. File name is the same as the subroutine name.
Lower case for Fortran variables.
Upper case for c-processor variables
Use variables ending with _ for parameter.
The definitions of the parameter variables appear in the include file, paramode

3.1 $DISK/libs/

- `configure-libs`: library compilation configuration script
- `Makefile.libs.in` & `Makefile.rlibs.in`: templates for creating libraries and constants
- ./con/: directory that contains globally shared constants and climatology files
- ./etc/: directory that contains miscellaneous utility files
- ./lib/: directory that specifies library sources

3.1.1 $DISK/libs/con/

(1) Climatology data files

Name	Description
clim.deepsoil.grib.Z	Deep soil wetness
clim.glacier.grib.Z	Permanent ice mask (0 or 1)
clim.ice.grib.Z	Sea ice mask
clim.matthewalb.grib.Z	Mathews albedo
clim.maxice.grib.Z	Maximum sea ice mask
clim.sibalbedo.grib.Z	Sib Albedo
clim.sibresis.grib.Z	Sib plant stoma resistance
clim.sibrough.grib.Z	Sib surface roughness
clim.sibveg.grib.Z	Sib vegetation cover
clim.sibvegidx.grib.Z	Sib vegetation type
clim.snow.grib.Z	Snow depth
clim.soiltype.grib.Z	Soil type
clim.soilwet.grib.Z	Soil wetness
clim.soilwet.r2.grib.Z	Soil wetness from reanalysis II
clim.sst.50-97.grib.Z	Sea Surface Temperature -- 1950-1997 climatology
clim.sst.grib.Z	Sea Surface Temperature
clim.tg3.grib.Z	Deep soil temperature
clim.vegfrac.grib.Z	Vegetation fraction
clim.vegtype.grib.Z	Vegetation type
clim.yhalbedo.grib.Z	Albedo

(2) Auxiliary constant files

Name	Description
aerdefb.asc.Z	aerosol concentration
cns_348_490670.asc.Z	CO2 concentration, 348 ppm covering the 490-670 wavenumber range
cns_348_490850.asc.Z	CO2 concentration, 348 ppm covering the 490-850 wavenumber range
cns_348_670850.asc.Z	CO2 concentration, 348 ppm covering the 670-850 wavenumber range
cns_350_490670.asc.Z	CO2 concentration, 350 ppm covering the 490-670 wavenumber range
cns_350_490850.asc.Z	CO2 concentration, 350 ppm covering the 490-850 wavenumber range
cns_350_670850.asc.Z	CO2 concentration, 350 ppm covering the 670-850 wavenumber range
gcmo3.asc.Z	ozone concentration
o3loss.clim.asc.Z	ozone loss coefficients
o3prod.clim.asc.Z	ozone production coefficients
top8m_avg.20i4.asc.Z	Orography with 8 minutes resolution -- average
top8m_max.20i4.asc.Z	Orography with 8 minutes resolution -- maximum
top8m_slm.80i1.asc.Z	Orography with 8 minutes resolution -- land-sea mask
top8m_var.20i4.asc.Z	Orography with 8 minutes resolution -- variance
tune.t42l18.amip.ewmrg.asc.Z	Cloud tuning table based on T42 L18 amip runs
tune.t62l28.reanl.ewmrg.asc.Z	Cloud tuning table based on T62 L28 reanalysis
tune1.asc.Z	Cloud tuning table where eastern and western tables are combined
tune1.mardec95_vvsyn.asc.Z	Operational MRF cloud tuning table based on Mar-Dec 1995 data
slmsk1x1.asc.Z	sea land mask in ascii format
slmsk1x1.ieee.Z	sea land mask in ieee format

(3) Files for case study and test run

Name	Description
clim.sibresis.old.grib.Z	Sib plant stoma resistance
clim.soilwetcpc.grib.Z	soil wetness
mdlv1e.asc.Z	model level
sfcanl90030900.asc.Z	Surface analysis for the 00Z, 03/09/1990 case
siganl90030900.asc.Z	Sigma analysis for the 00Z, 03/09/1990 case
snowanl.781201.grib.Z	Snow analysis for the 12/01/1978 case
sstanl.900309.grib.Z	Sea surface temperature from reanalysis
sstanl.900310.grib.Z	Sea surface temperature from reanalysis
sstanl.900311.grib.Z	Sea surface temperature from reanalysis

3.1.2 $DISK/libs/etc/

(1) Scripts_grib manipulator

Name	Description
grmap	grmap script - main driver
grmapsub	grmap sub script
grmean	Grib mean utility script
grsplit	Grib file splitting utility script
grtran	Grib file transpose utility script

(2) Scripts_templates

Name	Description
chgdates.in	script that changes date of sigma and sfc files
cray2ie3.in	Cray binary to ieee format converter
date.in	script that prints date from sigma and sfc files
fhour.in	Script that prints forecast hour from sigma and sfc files
ibm2ie3.in	cos blocked ibm format to ieee converter
ieee2grb_sst.in	Script that converts ieee sst files to grib format
incdte.in	Script that increments date
inchour.in;	Script that increments hour

(3) Scripts_miscellaneous

Name	Description
getfile	script that handles GRADS % format input
Jd	script that computes Julian day
mkdef	Scan program for xxx_ and put define at the beginning
mkdep	Scan program that searches include used in the program and add dependency lines at the end of Makefile file
mpiset	script that handles mpi setting
nmcdate	script that creates nmcdate file for given dates
renam	script that renames multiple files

(4) Tables

Name	Description
grib1.kpds5.vsn21	GRIB field identification table (reanalysis version)
grib1.kpds5.vsn22	GRIB field identification table (extended version)
grib1.kpds6.vsn21	GRIB field level identification table
Pentads	Table of pentads starting and ending dates

(5) Util directories

Name	Description
util_xxx	Directory that contains grmap, grmean, grsplit, grtan, ibm2ie3 and cray2ie3 source codes, xxx (machine)= cray, dec, hp, ibmsp, linux, origin, sgi, sun, t3e, t90
utils	Directory that contains chgdates, date, ifdef, ieee2grib, incdtc, inchour, mpiset, force_grib_date_mon source codes

3.1.3 $DISK/libs/lib/=>|-/w3lib_xxx /
|-/modelib/
|-/ncaru/

(1) ./w3lib_xxx /

a) Table 1 -- subprograms needed for all machines

Name	Description
aea.f	subroutine that converts ASCII to/from EBCDIC
baread.f	subroutine that extracts fragments of bytes from an unblocked file
datimx.f	subroutine that provides date and time information
gbytes.f	subroutine that unpacks bits to get bytes
getgbss.f	subroutine that finds a grib message
getgir.f	subroutine that reads a grib file and returns its index contents
Iw3jdn.f	subroutine that computes Julian day
Iw3pds.f	subroutine that tests whether two pds (grib product definition section) are equal
ixgb.f	subroutine that makes index record
pdsens.f	subroutine that packs grib pds extension starting byte 41 and above
pdseup.f	subroutine that unpacks grib pds extension starting on byte 41 for ensemble forecast products
rdgb.f	subroutine that reads grib message(check!!)
skgb.f	subroutine that searches for next grib message
unpindx.f	subroutine that unpacks a grib index buffer
W3fi01.f	subroutine that determines the number of bytes in a full word
W3fi04.f	subroutine that finds word size, endian type, and chacater set
W3fi63.f	subroutine that unpacks a grib field to the exact grid specified in the grib message
W3fi83.f	subroutine that restores delta packed data to original values
W3fp11.f	subroutine that converts pds to one-line grib title
W3fs26.f	subroutine that computes year, month, day, day of week, day of year from Julian day number
W3tagb.f	subroutine that prints operational job identifier
xmovex.f	subroutine that removes data

b) Table 2 -- subprograms needed for the particular machine(s)

Name	Description	Machine(s)
0gbyte.f	Fortran version of gbyte.f for Sun Sparcstation	sun only
0gbytes.f	Fortran version of gbytes.f for Sun Sparcstation	sun only
0sbyte.f	Fortran version of sbyte.f for Sun Sparcstation	sun only
0sbytes.f	Fortran version of sbytes.f for Sun Sparcstation	sun only
1sbyte.f	subroutine that packs integer to character	hp and sun
1sbytes.f	subroutine that employs 1sbyte.f to pack character	hp and sun
2gbyte.f	Fortran version of gbyte.f for Sun Sparcstation	sun only
2gbytes.f	Fortran version of gbytes.f for Sun Sparcstation	sun only
2sbyte.f	Fortran version of sbyte.f for Sun Sparcstation	sun only
2sbytes.f	Fortran version of sbytes.f for Sun Sparcstation	sun only
assign.f	a dummy subroutine	all except for cray
baopen.f	subroutine that opens a file to be accessed by baread or bawrite	all except for hp and sun
cdate.c	subroutine that constructs month, day, and year	hp and ibmsp
cdate2.c	subroutine that constructs month, day, and year	ibmsp only
compallg.sh	script that compiles subroutines in the w3lib.a library	sun only
compw3.sh	script that provides Fortran complier option for w3lib	sun only
gbyte.f	subroutine that employs gbytes.f to get bytes	all except for cray
sbyte.f	subroutine that packs integer into character	all except for hp
sbytes.f	subroutine that employs sbyte.f to pack character	all except for hp
swap32.f	subroutine that reverses order of bytes	dec and linux
under.c	subroutine that checks floating point	origin, t3e, and t90
w3fi58.f	subroutine that packs positive differences in least bits	cray, t3e, and t90
w3fi59.f	subroutine that forms and packs positive, scaled differences	cray, t3e, and t90
w3fi68.f	subroutine that converts 25 word array to grib pds	cray, t3e, and t90
w3fi71.f	subroutine that make array used by grib packer	cray, t3e, and t90
w3fi72.f	subroutine that makes a complete grib message	cray, t3e, and t90
w3fi73.f	subroutine that constructs grib bit map section	cray, t3e, and t90
w3fi74.f	subroutine that constructs grib definition section	cray, t3e, and t90
w3fi75.f	subroutine that packs a grib field and forms octets	cray, t3e, and t90

w3fi76.f	subroutine that converts floating point number	cray, t3e, and t90
w3fi82.f	subroutine that converts array to second differences	cray, t3e, and t90
w3pack.f	subroutine that packs positive differences in least bits	all except for cray. t3e, and t90
w3ft33.f	subroutine that thickens thinned wafs grib grid	ibmsp
xstore.f	subroutine that stores a constant value into array	cray, t3e, and t90

(2) ./ncaru=>|-lib/
|-utils/

(a) ./ncaru/lib

Name	Description
CVS	CVS administrative directory
Makefile.in	Makefile template for building libncaru.a
cray.c	C routine covering various user entry points
cray.h	file containing definitions for cray dataset routines and possible operations
ctodpf.c	C routine that converts Cray to IEEE double precision
ctosp.c	C routine that converts Cray to IEEE single precision
dptocf.c	C routine that converts IEEE double precision (floating) to Cray
dptoci.c	C routine that converts IEEE double precision (integer) to Cray
sptoc.c	C routine that converts IEEE single precision to Cray

(b) ./ncaru/utils

Name	Description
CVS	CVS administrative directory
Makefile.in	Makefile template for building the utilities
cosconvert.c	C routine that strips Cray blocking from a file
cosfile.c	C routine that examines a blocked file and reports record size
cossplit.c	C routine that splits a multiple Cray blocked dataset into separate files

(3) ./modelib: contains model library source

Name	Description
bsslz1.f	subroutine that computes latitude points by iteration
fft99m.f	subroutine that performs fast Fourier transform
filtcof.f	subroutine that computes coefficients for time smoothing
gaulat.f	subroutine that computes Gaussian latitudes from a given truncation
gl2gl.f	subroutine that interpolates from gaussian grid to other gaussian grid
glats.f	subroutine that computes Gaussian latitudes related arraies
grmget.f	subroutine that searches multiple grib files from matching multiple fields and retrieve the fields
grmgeta.f	subroutine that searches multiple grib files from matching multiple fields and retrieve the fields
grmgetb.f	subroutine that searches multiple grib files from matching multiple fields and retrieve the fields
grmput.f	subroutine that creates a grib record from a full field
gspc.f	subroutine that computes utility spectral fields
gtbits.f	subroutine that computes number of bits and round field
idsdef.f	subroutine that sets default decimal scaling for grib message
iminv.f	subroutine that inverts a matrix
incdte.f	subroutine that computes year,month,day, and hour of forecast
maxmin.f	subroutine that prints maximum and minimum values and locations of a given array
parzen.f	subroutine that computes parzen window weight
pder.f	subroutine that computes legendre polynomials derivatives
pleg.f	subroutine that computes legendre polynomials
poly.f	subroutine that computes latitude points by iteration
rmaxmin.f	subroutine that prints maximum and minimum of a given array
Sg2sg.f	subroutine that transfers from one defined sigma coordinate to another sigma coordinate
tridi2.f	subroutine that solves tridiagonal matrix problems
trispl.f	subroutine that calculates weights for cubic spline interpolation
valts.f	subroutine that calculates interpolated values of function using weights calculated by trispl
wryte.f	subroutine that writes data out by bytes
ysminv.f	subroutine that computes inverse of matrix

3.2 $DISK/srcs/

- `configure-model`: source code compilation configuration script
- `Makefile.rsm.in`: template for creating executables
- ./def/: directory that defines parameters and constants depending on model resolution, model options, and machine types.
- ./opt/: directory that contains model compiler options for various machine types.
- ./src/: directory that contains model source code.
- ./bin/: directory that contains model executables. The bin directory is generated after compilation of the code.

3.2.1 $DISK/srcs/def/

- function.h: define machine dependent statement
- Directories with varying `model resolution`: specifies model options and resolution-dependent paramaters and constants

Directories for a range of GSM and RSM model resolution

Name	Description
Gsm12628	**GSM with T126 truncation and 28 levels**
Gsm17042	**GSM with T170 truncation and 42 levels**
Gsm32042	**GSM with T320 truncation and 42 levels**
Gsm4218	**GSM with T42 truncation and 18 levels**
Gsm4228	**GSM with T42 truncation and 28 levels**
Gsm6228	**GSM with T62 truncation and 28 levels**
Rsm4218r5455	**RSM with 54x55 grids using T42L18 GSM base**
Rsm6228r10869	**RSM with 108x69 grids using T62L28 GSM base**
Rsm6228r12885	**RSM with 128x85 grids using T62L28 GSM base**
Rsm6228r162105	**RSM with 162x105 grids using T62L28 GSM base**

Each directory contains:

- `define.h`: defines resolution-dependent parameters and model options
- `modlsigs.h`: defines model levels
- `postplevs.h`: defines pressure levels
- Users can always create a separate directory depending on user-specified model resolution

3.2.2 $DISK/srcs/opt/

- Contains files that specify compiler options.
- The naming convention for these files is `options-MACHINE-MARCH`, where `MACHINE` and `MARCH` are machine type and machine functionality, respectively.

Table for current status of RSM compiler options as of January 2001.

MACHINE	MARCH =single	MARCH =thread	MARCH =mpi	MARCH =hybrid
c90	yes	yes	No	no
cray	yes	yes	No	no
dec	yes	no	No	no
hp	yes	no	No	no
ibmsp	yes	yes	No	no
linux	yes	no	No	no
origin	yes	yes	No	no
sgi	yes	No	No	no
sun	yes	No	No	no
t3e	yes	No	No	no
t90	yes	yes	no	no

3.2.3 $DISK/srcs/src/

1) Directories for both GSM and RSM

- /albaer/: contains Yutai's albedo interpolation program sources
- /chgdates/: contains program sources for changing the date of sig/sfc files
- ./chgr/: contains resolution change sources
- ./cldtune/: contains cloud tuning program sources
- ./cnvaer/: contains program sources for processing aerosol data
- ./cnvalb/: contains program sources for processing albedo data
- ./cnvrt/: contains program sources that convert sig/sfc files to native format
- ./co2/: contains CO2 vertical interpolation sources
- ./fcst/: contains program sources for model dynamics, physics, and I/O

- ./include/: contains include files (*.h) for constant parameters and common blocks
- ./mpi/: contains a package linking model and MPI system library
- ./mtn/: contains global model orography progarm sources
- ./sfc/: contains interpolation and merge program sources for surface fields, merging of seasonally varying climatological data, observed analysis data, and GSM forecasted surface fields every specified interval (e.g., 24 hours)
- ./share/: contains model share program sources

2) Directories only for GSM

- ./pgb/: contains gribbing program sources at pressure levels
- ./sgb/: contains gribbing program sources at sigma levels

3) Directories only for RSM

- ./rfcst/ (rfcst.x): contains main program source driving RSM forecast.
- ./rgsm/ (rgsm.a): contains model physics routines, which are linked directly to ./fcst/ directory
- ./rinpg/ (rinpg.x): contains interpolation program sources from global to regional grid or from coarse regional to fine regional grid
- ./rmrgsfc/ (rmrgsfc.x): contains merge program sources for regional surface fields (merge RSM forecasted surface fields with ones interpolated from global to regional grid)
- ./rmtn/ (rmtn.x): contains program sources for obtaining regional topography and its variance
- ./rpgb/ (rpgb.x): contains gribbing program sources at pressure levels in regional grid
- ./rsfc/ (rsfc.x): contains interpolation and merge program sources for surface fields copied directly from ./sfc/ directory, merging of seasonally varying climatological data, observed analysis data, and RSM forecasted surface fields every specified interval (e.g., 24 hours)
- ./rsgb/ (rsgb.x): contains gribbing program sources at sigma levels in regional grid
- ./rsml/ (rsm.a): contains program sources for RSM model dynamics and I/O

3.3 $DISK/run/

- `configure-scr`: run scripts configuration script
- `rsm.in`: template for main run script
- ./runscr/: directory that contains various run scripts called by the main run script (`rsm.in`).

3.3.1 $DISK/run/runscr

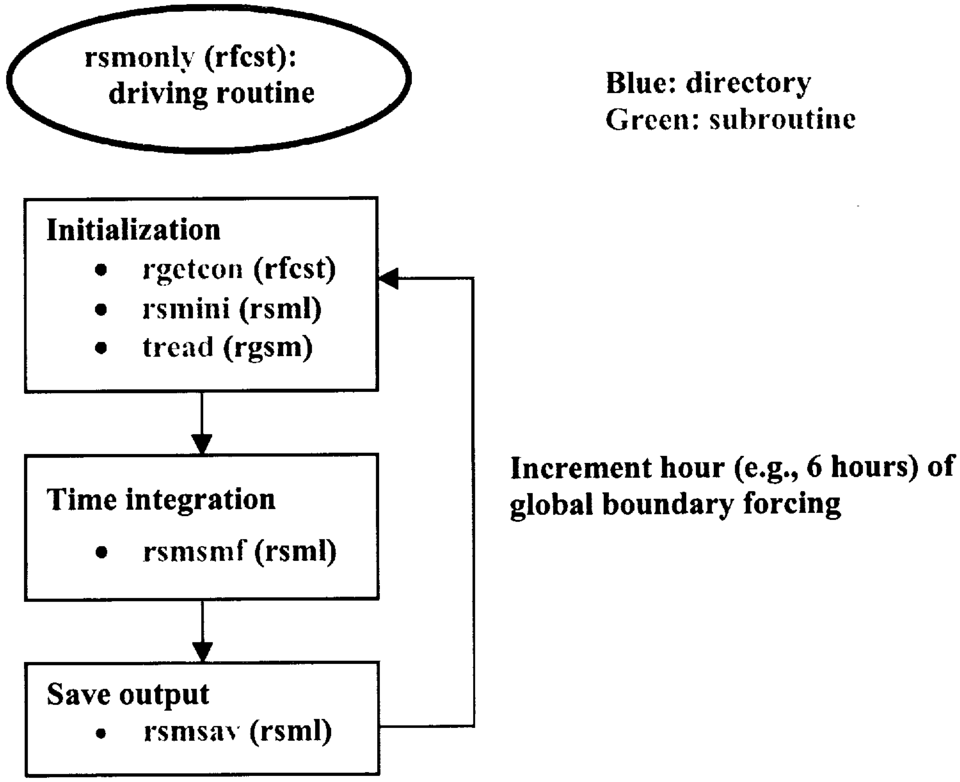
Run script templates

Name	Description
chgdates.in	**change date**
chgr.in	**change resolution**
cnv4dig.in	**convert 2-digit year to 4-digit year**
cnvrt.in	**convert input file from original to native format**
fcst.in	**execute global forecast**
pgb.in	**generate GSM grib format output at pressure levels**
sfc.in	**merge of seasonally varying climatological data, observed analysis data, and GSM forecasted surface fields**
rfcst.in	**execute regional forecast**
rinpg.in	**execute interpolation program from global to regional grid**
rmtn.in	**obtain topography data and its variance**
rpgb.in	**generate RSM grib format output at pressure levels**
rsfc.in	**merge of seasonally varying climatological data, observed analysis data, and RSM forecasted surface fields**
rsfcm.in	**interpolate global surface field to regional grid and merge with regional forecast surface field**

4. Model Integration Road Map

($DISK/srcs/src/)

Blue: directory
Green: subroutine



4.1 Initialization

rgetcon (rfcst):

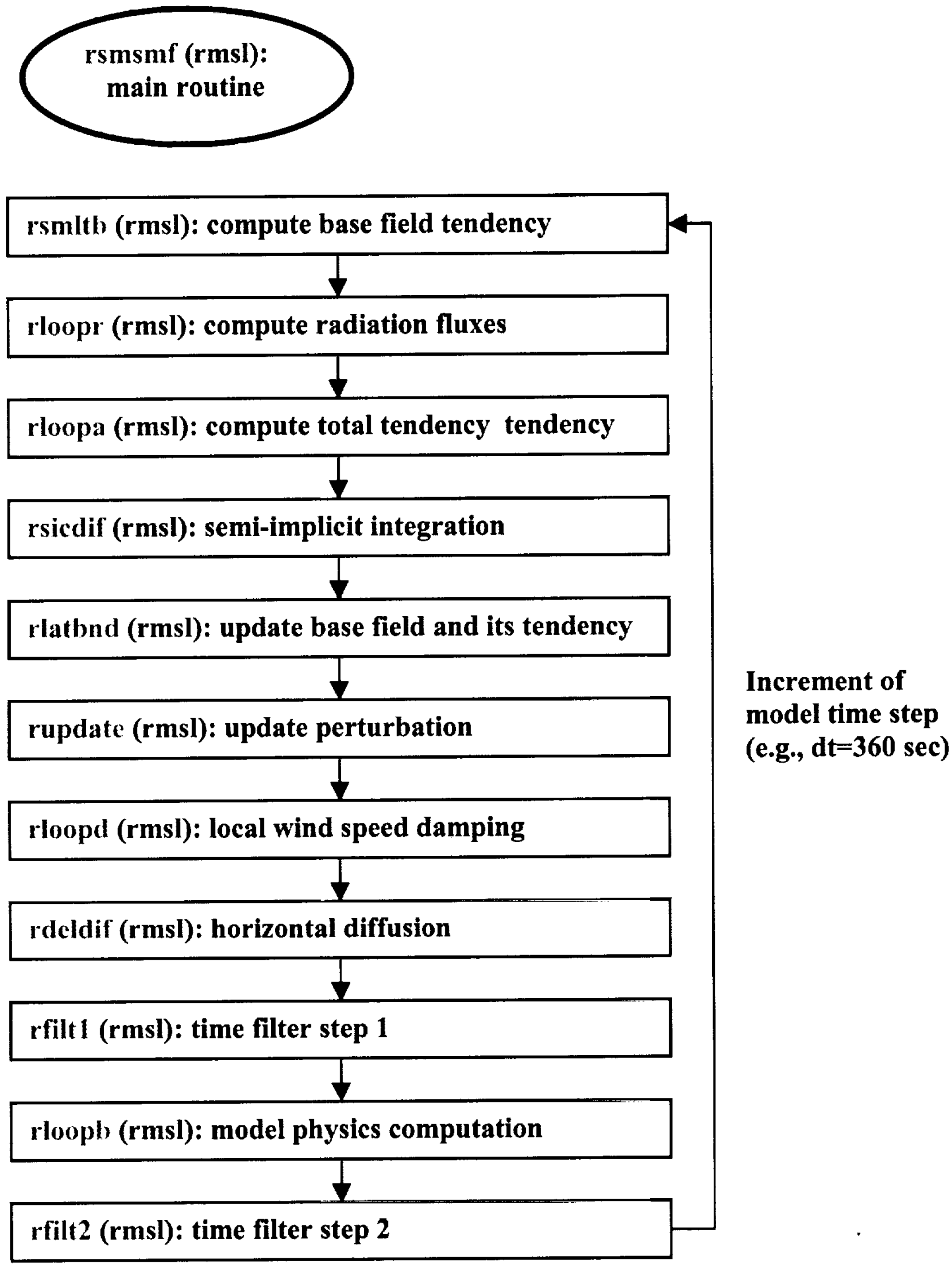
- set model integration constants
- set table for model physics

rsmini (rsml):

- set more constants beyond rgetcon
- rsminp (rsml)
  - read global base field
    - gsm2bgd (rsml): transform spectral global input field to regional grid
    - sread (rsml): read regional sigma field to obtain regional perturbation in wave coefficients
- rfixio (rsml): read regional surface fields

tread (rgsm): read next global base field

4.2 Time integration



4.3 Save output

rsmsav (rmsl)

swrite (rmsl): output regional sigma file (r_sigft.ftxx)

rloopz (rmsl) [call rwrtsfc(rsml)]: output regional flux file (r_flx.ftxx)

rfixio (rmsl): output regional surface file (r_sfcft.ftxx)

5. Model IO

5.1 IO file types:

1) binary format files (8 bytes for float-point number, 4 bytes for integer number)

- sigma file (r_sig*): contains prognostic fields on model $\sigma(\equiv P/P_s)$-level
- surface file (r_sfc*): contains fields besides the sigma file most of which are surface fields
- flux file (r_flx*): contains diagnostic fields

2) grib format files

- r_pgb* [rpgb1(rpgb), gribit(share)]: grib files on pressure surface created from the sigma and flux binary files
- r_sgb*: grib files on pressure surface created from the sigma and flux binary files

5.2 IO variables

1) **sigma file variables**

- wave coefficients for global base data
- grid values for regional forecast output

gz	surface height (m)
q	ln(P_s) in centibar (P_s: surface pressure)
te	virtual temperature (K)
di or uu	divergence (s^{-1}) x-axis wind (m/s)
ze or vv	vorticity (s^{-1}) y-axis wind (m/s)
rq	specific humidity or waters (g/g)

2) surface file variables

*: predicted or estimated, the others are from climatology, observation, reanalysis, or global forecast

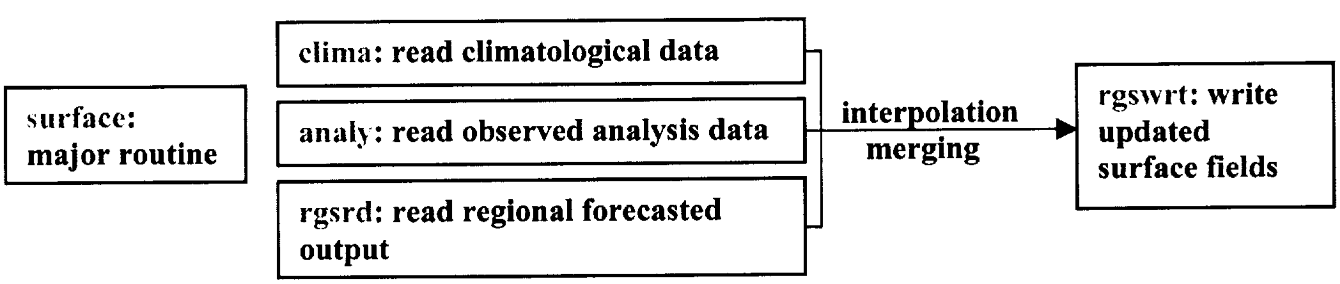
tsea*	surface temperature (K) [* over land]
smc*	soil moisture content (fraction)
	smc(*,1): mean from 0 to -100mm
	smc(*,2): mean from -100 to -2000mm
sheleg*	snow depth (mm)
stc*	soil temperature (K)
	stc(*,1): mean from 0 to -100mm
	stc(*,2): mean from -100 to -2000mm
tg3	deep soil temperature (K)
	mean from -2000mm to -4000mm
zorl*	surface roughness (mm) [* over ocean]
cv*	cloud cover
cvb*	cloud base height
cvt*	cloud top height
albed	surface albedo (fraction, 4 types)
slmsk	sea land and sea ice mask (0=sea, 1=land, 2=sea ice)
vfrac	vegetation cover (fraction)
hprime	mountain variance
canopy*	surface canopy water content
f10m	factor for 10 m wind (only used by data assimilation)
vtype	vegetation type (13)
stype	soil type (9)
facalf	zeneith angle dependent vegetation fraction
ustar*	surface friction velocity
fm*	integrated profile function for momentum in the surface layer
fh*	integrated profile function for heat and moisture in the surface layer

<u>**Update of surface fields**</u>

Non-predicted surface fields are updated every user specified interval (e.g., 24hr) from

(1) climatology or observation, or
(2) reanalysis or global forecast data

(1) $DISK/srcs/src/rsfc/



(2) $DISK/srcs/src/

s2rinp (./rsml/) called by reginp (./rinpg/): read global or reanalysis surface fields and interpolate them into regional grids

→

mrgsfc (./rmrgsfc/): read interpolated surface fields and regional forecasted output, then merge together

3) flux file variables

dusfc	mean u momentum flux at surface
dvsfc	mean v momentum flux at surface
dtsfc	mean sensiable heat flux at surface
dqsfc	mean latent heat flux at surface
tsea	surface temperature
smc	first soil layer moisture content
smc	second soil layer moisture content
stc	first soil layer temperature
stc	second soil layer temperature
sheleg	water equivalent snow depth
dlwsfc	mean downward longwave radiation at surface
ulwsfc	mean upward longwave radiation at surface
ulwtoa	mean upward long wave radiation at top atmosphere
uswtoa	mean upward solar radiation at top atmosphere
uswsfc	mean upward solar radiation at surface
dswsfc	mean downward solar radiation at surface
tcdchcl	mean total cloud cover for high cloud
preshct	pressure of cloud top for high cloud
preshcb	pressure of cloud base for high cloud
tmphct	temperature of cloud top for high cloud
tcdcmcl	mean total cloud cover for middle cloud
presmct	pressure of cloud top for middle cloud
presmcb	pressure of cloud base for middle cloud
tmpmct	temperature of cloud top for middle cloud
tcdclcl	mean total cloud cover for low cloud
preslct	pressure of cloud top for low cloud
preslcb	pressure of cloud base for low cloud
tmplct	temperature of cloud top for low cloud
geshem	mean total precipitation
bengsh	mean convective precipitation
gflux	mean total ground flux
slmsep	mask for sea and land
slmsep	mask for sea ice
u10	10 m u wind
v10	10 m v wind
t2	2 m temperature
q2	2 m specific humidity

psurf	ground surface pressure
tmpmax	maximum of T2 during the integration period
tmpmin	minimum of T2 during the integration period
runoff	water runoff
ep	mean surface evaporation
cldwrk	mean cloud work function
dugwd	mean gravity-wave drag flux for u
dvgwd	mean gravity-wave drag flux for v
hpbl	height of PBL
pwat	precipitable water
albed	albedo
tcldc	total cloud cover

5.3 GrADS plotting grib output

- Install GrADS graphic package
- Set path to $DISK/libs/etc/ in .cshrc or .profile
- Type grmap [grib file name (r_pgb*)] , which generates GrADS control file (*.ctl)
- Type
  gribmap —i [control file name (*.ctl)]
  (gribmap -o: ignore the forecast time
  in the mapping; only use the base time)
- On GrADS mode (by typing grads),
  type open [control file name (*.ctl)]
- Plot model output fields by typing
  d [variable name]

An example of GrADS control file (r_pgb.ctl)

```
dset /rsm/run/r_000/r_pgb.ft24
dtype grib
index /rsm/run/r_000/r_pgb.ft24.r_pprs.idx
undef -9.99E+33
title EXP
pdef   109   70 nps   53.999  224.000  -93.000   30.000
xdef  1200 linear      .000    .300
ydef   201 linear   29.000    .300
zdef    12 levels
    1000  925  850  700  600  500  400  300  250  200
     150  100
tdef    1 linear             12Z15MAY1995     24hr
vars    72
HGTprs    12 7,100,0 Geopotential height (gpm)
```

```
UGRDprs    12 33,100,0 u wind (m/s)
VGRDprs    12 34,100,0 v wind (m/s)
TMPprs     12 11,100,0 Temperature (K)
VVEL       12 39,100,0 Pressure vertical velocity (Pa/s)
RHprs      12 52,100,0 Relative humidity (percent)
ABSV       12 41,100,0 Absolute vorticity (/s)
PRESsfc     0 1,1,0 Pressure (Pa)
PTEND       0 3,1,0 Pressure tendency (Pa/s)
PWAT        0 54,200,0 Precipitable water (kg/m**2)
RHclm       0 52,200,0 Relative humidity (percent)
TMPtrp      0 11,7,0 Temperature (K)
PREStrp     0 1,7,0 Pressure (Pa)
UGRDtrp     0 33,7,0 u wind (m/s)
VGRDtrp     0 34,7,0 v wind (m/s)
VSSH        0 136,7,0 Vertical speed shear (1/s)
LFTX        0 131,1,0 Surface lifted index
4LFTX       0 132,1,0 Best (4-layer) lifted index
TMPmwl      0 11,6,0 Temperature (K)
PRESmwl     0 1,6,0 Pressure (Pa)
UGRDmwl     0 33,6,0 u wind (m/s)
VGRDmwl     0 34,6,0 v wind (m/s)
HGTsfc      0 7,1,0 Geopotential height (gpm)
PRMSL       0 2,102,0 Pressure reduced to MSL (Pa)
UFLX        0 124,1,0 Zonal component of momentum flux
                (N/m**2)
VFLX        0 125,1,0 Meridional component of momentum flux
                (N/m**2)
SHTFL       0 122,1,0 Sensible heat flux (W/m**2)
LHTFL       0 121,1,0 Latent heat flux (W/m**2)
TMPsfc      0 11,1,0 Temperature (K)
WEASD       0 65,1,0 Water equiv. of accum. snow depth
                (kg/m**2)
DLWRF       0 205,1,0 Downward long wave radiation flux
                (W/m**2)
ULWRFsfc    0 212,1,0 Upward long wave radiation flux
                (W/m**2)
ULWRFtoa    0 212,8,0 Upward long wave radiation flux
                (W/m**2)
USWRFtoa    0 211,8,0 Upward solar radiation flux (W/m**2)
USWRFsfc    0 211,1,0 Upward solar radiation flux (W/m**2)
DSWRF       0 204,1,0 Downward solar radiation flux (W/m**2)
TCDChcl     0 71,234,0 Total cloud cover (percent)
PREShct     0 1,233,0 Pressure (Pa)
PREShcb     0 1,232,0 Pressure (Pa)
TMPhct      0 11,233,0 Temperature (K)
TCDCmcl     0 71,224,0 Total cloud cover (percent)
PRESmct     0 1,223,0 Pressure (Pa)
```

```
PRESmcb     0 1,222,0 Pressure (Pa)
TMPmct      0 11,223,0 Temperature (K)
TCDClcl     0 71,214,0 Total cloud cover (percent)
PRESlct     0 1,213,0 Pressure (Pa)
PRESlcb     0 1,212,0 Pressure (Pa)
TMPlct      0 11,213,0 Temperature (K)
PRATE       0 59,1,0 Precipitation rate (kg/m**2/s)
CPRAT       0 214,1,0 Convective precipitation rate
                      (kg/m**2/s)
GFLUX       0 155,1,0 Ground heat flux (W/m**2)
LAND        0 81,1,0 Land-sea mask (1=land; 0=sea) (integer)
ICEC        0 91,1,0 Ice concentration (ice=1; no ice=0)
                     (1/0)
UGRDhag     0 33,105,0 u wind (m/s)
VGRDhag     0 34,105,0 v wind (m/s)
TMPhag      0 11,105,0 Temperature (K)
SPFH        0 51,105,0 Specific humidity (kg/kg)
SFCR        0 83,1,0 Surface roughness (m)
TMAX        0 15,105,0 Maximum temperature (K)
TMIN        0 16,105,0 Minimum temperature (K)
RUNOF       0 90,1,0 Runoff (kg/m**2)
PEVPR       0 145,1,0 Potential evaporation rate (w/m**/)
CWORK       0 146,200,0 Cloud work function (J/Kg)
UGWD        0 147,1,0 Zonal gravity wave stress (N/m**2)
VGWD        0 148,1,0 Meridional gravity wave stress
                      (N/m**2)
HPBL        0 221,1,0 PBL height (m)
ALBDO       0 84,1,0 Albedo (percent)
TCDCclm     0 71,200,0 Total cloud cover (percent)
CDCON       0 72,200,0 Convective cloud cover (percent)
SRWEQ       0 64,200,0 Snowfall rate water equivalent
                       (kg/m**2/s)
SNOEV       0 230,200,0 Snow sublimation heat fulx (W/m**2)
SNOHF       0 229,200,0 Snow melt heat flux (W/m**2)
endvars
```

6. Setting-up Experiment and Model Run Procedure

6.1 Make model library

```
cd $DISK/libs
edit  configure-libs  and set
        MACHINE=[sgi/origin/ibmsp/sun/dec/hp/cray/t90/t3e/linux]
type  configure-libs
type  make
```

6.2 Compile model source code

```
cd $DISK/srcs
edit  configure-model  and set
    CPSLIBS_DIR, MODEL, MODEL_DEFINE, MARCH, NCPUS, NPES
modify  define.h  in $DISK/srcs/def/rsm$$$$r####/
type  configure-model
type  make'
```

Setting parameters in configure-model

```
CPSLIBS_DIR=$DISK/libs/   :directory name that contains model library
MODEL=rsm    :model type
MODEL_DEFINE=‘pwd‘/def/${MODEL}6228r9669
        :directory name that contains model configuration such as model
         resolution, constant parameters, and model options
         rsm$$$$r####:
            $$$$=global base field resolution
            ####=regional grid resolution
         rsm6228r9669: experiment with T62L28 global base field and 96x69
                       regional grid resolution
MARCH=thread  :machine cpu usage type (single/mpi/thread/hybrid)
NCPUS=4       :number of cpus or threads (when MARCH != single)
NPES=1        :number of pes or nodes (when MARCH=mpi or hybrid)
```

$DISK/srcs/def/define.h

```
#include <machine.h>

#define _jcap_ 62
#define _levs_ 28
#define _lonf_ 192
#define _latg_ 94

#define _lsoil_ 2
#define _lalbd_ 4
#define _mtnres_ 8

#define _ntrac_ 1
#define _ncldg_ 0
#define _nstype_ 9
#define _nvtype_ 13

#define NEWSFC
#undef NEW_EDIR
#undef NEWGWD
#undef RAD_SMOOTH_CLOUD
#undef REDUCE_GRID
#undef SKIPSFCMRG
#undef CLDADJ
#undef RADMDC
#undef CLDSLINGO

#undef FX
#undef DBG
#undef DG
#undef DGZ
#undef DG3
#undef DGM
#undef KEN
#undef CLR
#undef SIB
#undef WAV
#define SAS
#undef RAS
#undef RASV2
#undef CCMCNV
#undef CCMSCV
#undef DFI
#define SFC
#undef LNEWSFC
#define _nvect_ 64
#define _lpnt_ 30
#define _ltstp_ 42
#define _slvark_ 80
#define _mlvark_ 8

#define _igrd_ 96
#define _jgrd_ 69
#define _levr_ 28
#define _cigrd1_ 192
#define _cjgrd1_ 94
#define _relx_ 5
#define _border_ 3
#define _bgf_ 3
#define _difuh_ 3.
#define _difum_ 2.

#define _lonssi_ 256
#define _maxlev_ 200000
#define _maxrep_ 40000
#define _maxcyl_ 25000
#define _maxpak_ 5000
#define _nqc_ 4
#define _nmx_ 64
#define _n_ 10

#define _ntdata_ 25000
#define _nsdata_ 5000
#define _nwdata_ 25000
#define _npdata_ 5000
#define _nqdata_ 15000
#define _npwdat_ 1
#define _nsprof_ 2000
#define _nsigdivt_ 28
#define _jcapdivt_ 62
#define _jcapstat_ 62
#define _nmdszh_ 28
#define _nsigsat_ 28
#define _ilonf_ 192
#define _ilatg_ 94
#define _ijcap_ 62
#define _ilevs_ 28

#define _io_ 144
#define _jo_ 73
#define _ko_ 12
#define _kt_ 6
#define _ktt_ 1
#define _kzz_ 1
#define _moo_ 1

#define _igrdp_ 1
#define _jgrdp_ 1

#if (__nstype_ == 16)
#define NEWSFC
#define NEW_EDIR
#define STATSGO_SOIL
#endif

#if (_ncldg_ == 0)
#undef ICE
#undef ICECLOUD
#else
#define ICE
#define ICECLOUD
#endif

#if (_ncldg_ == 1)
#define CLD2
#endif

#undef NEWALB
#ifdef NEWSFC
#define NEWALB
#endif

#define INTERACTIVE_STRATUS
#if (_ncldg_ == 0)
#undef INTERACTIVE_STRATUS
#endif

#ifdef NEWGWD
#define _mtnvar_ 10
#else
#define _mtnvar_ 1
#endif

#undef LFM
#undef LFC

#define RSM
#define SQK
#undef SPT
#define G2R
#undef C2R
#undef NOPRINT
#undef MP
```

Defining constant parameters

```
jcap 62     : global truncated wave number
levs 28     : number of global vertical sigma levels
lonf 192    : number of global E-W Gaussian grids
latg 94     : number of global N-S Gaussian grids
             (relationship between jcap and lonf and latg:
              lonf ≥ 3*jcap+1,latg ≥ (3*jcap+1)/2)
lsoil 2     : number of soil layers
lalbd 4     : number of albedo types
mtnres 8    : topography resolution in minute (8min~15km)
ncldg 0     : number of prognostic cloud species
              (cloud water/ice, rain/snow)
nstype 9    : number of soil types
nvtype 13   : number of vegetation types
igrd 96     : number of regional x-axis grids
              (should be a product of integer powers of 2,3,5)
jgrd 69     : number of regional y-axis grids
              (should be an odd number)
levr 28     : number of regional vertical sigma levels
cigrd1 192  : number of coarse regional x-axis grids
cjgrd1 94   : number of coarse regional y-axis grids
relx 5      : lateral boundary relaxation
              parameter in terms of number of time steps
              (relx*Δt = 1800-3000 sec recommended,
               larger number implies less relaxation)
border 3    : interpolation order (3: cubic)
bgf 3       : interpolation parameter (bgf*Δx should be
              approximately equal to or less than base field
              grid size)
difuh 3     : numerical diffusion parameter for temperature and
              moisture in terms of number of time steps
              (larger number implies less diffusion)
difum 2     : numerical diffusion parameter for momentum
              in terms of number of time steps
              (larger number implies less diffusion)
ilonf 192   : number of E-W Gaussian grids in global input data
ilatg 94    : number of E-W Gaussian grids in global input data
ijcap 62    : truncated wave number in global input data
ilevs 28    : number of vertical sigma levels in global input data
```

Defining model option parameters

```
#define NEWSFC    : if defined, use new surface physics
#undef NEWGWD     : if defined, use new gravity wave drag
                    formulation
#undef CLDADJ     : if defined, conduct cloud adjustment
#define SAS       : if defined, simplified Arakawa-Schubert
                    cumulus cloud scheme
#undef RAS        : if defined, relaxed Arakawa-Schubert cumulus
                    cloud scheme
#if (_ncldg_==0)
#undef ICE
#undef ICECLOUD
#else             : for consideration of the effect of ice
#define ICE         and ice cloud on radiation
#define ICECLOUD
#endif

#undef NEWALB
#ifdef NEWSFC     : if NEWSFC is defined,
#define NEWALB      use new albedo types
#endif

#define G2R       : if defined, nesting from
                    global to regional grid
#undef C2R        : if defined, nesting from
                    coarse to fine regional grid
```

- After editing configure-model and modifying define.h in $DISK/srcs/def/rsm$$$$r####/, type configure-model , and it will generate files of define.h , machine.h , and options in $DISK/srcs/ where the configure-model is located.

- Before compiling the source code, it is recommended to check those files of define.h , machine.h , and options if the settings are correct.

- Then, start compilation by typing make , and it will generate many executables, source code libararies, and mountain and co2 data sets in the directory of $DISK/srcs/bin/.

6.3 Execute the model

```
cd $DISK/run
edit configure-scr and set MODEL_DIR
modify rsm.in
type configure-scr rsm
type rsm or submit rsm as batch job
```

- set parameters in configure-scr
  MODEL_DIR=$DISK/srcs/ :directory name that contains model source code

- modify rsm.in (run script template) or rsm (run script, generated by typing configure-scr rsm)

- configure-scr rsm also creates all run scripts in $DISK/run/runscr/ from their templates

Main run script (rsm) structure

specify run parameters

↓

```
if [-s restart files] then
    restart the run
else
                        | rmtn
                        | cnvrt
    initial start       | chgr
                        | cnv4dig
                        | rinpg
fi
```

↓

```
   h=current forecast hour
  hx=h + increment hour

while [ h < (end hour) ] do
        cnvrt (hx)
        chgr (hx)
        cnv4dig (hx)
        rsfc or rsfcm (h)
        rfcst (h to hx)
        rpgb (hx)
done
```

Run parameters

```
RUNNAME=r_000        : name of run working and output directory
FCST_RESTART=yes
INCHOUR=6            : base field increment hour
RDELT=360            : integration time step (second)
NESTING_HOUR=6       : nesting hour
ENDHOUR=720          : forecast ending hour
RSFC_CYCLE=yes       : if yes, use climatological or observation
                       data for non-predicted surface fields
RSFC_MERGE=no        : if yes, use reanalysis or global forecast
                       data for non-predictedurface fields
INPUT_RESOLUTION=t@JCAP@k@LEVS@
CHANGE_RESOLUTION=yes
SST_ANL=@CPSLIBS_DIR@/con/sstanl.900309.grib
                       : SST file option
ICE_ANL=climatology    : ice file option
SNO_ANL=guess          : snow file option
```

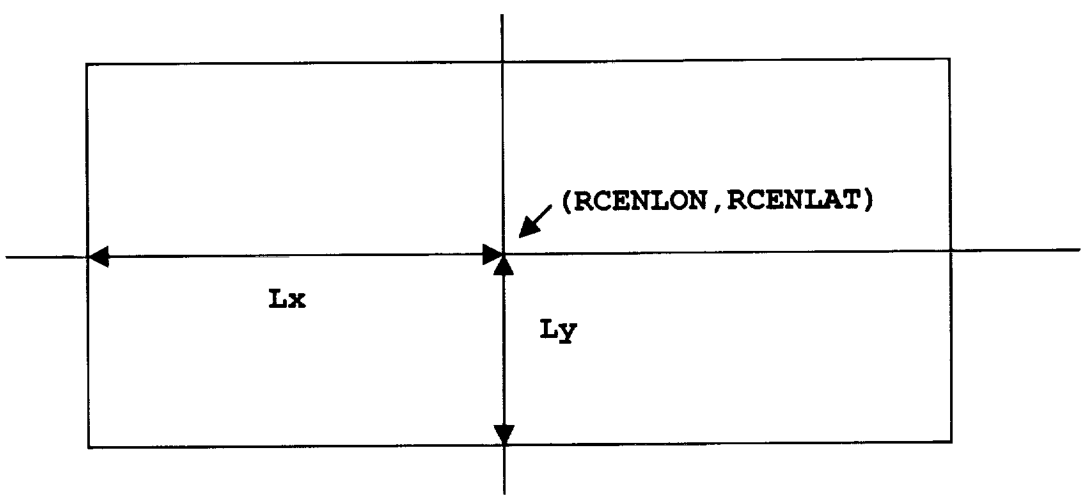
```
<mapping and domain parameters>
RPROJ=1
RTRUTH=60
RORIENT=-100
RDELX=60000
RDELY=60000
RCENLAT=90
RCENLON=0
RLFTGRD=49
RBTMGRD=134
NEW_CLIM_O3=yes
lnewsfc=.false.
SFC_EXEC_FREQ=24  : surface cycle frequency
sfc_freq=$SFC_EXEC_FREQ
SWHR_GBL=3   : computation interval(hour) for
               short wave radiation in GSM
LWHR_GBL=3   : computation interval(hour) for
               long wave radiation in GSM
SWHR_REG=1   : computation interval(hour) for
               short wave radiation in RSM
LWHR_REG=1   : computation interval(hour) for
               long wave radiation in RSM
LOCDF_REG=0 : local wind speed dependent damping (0:off, 1:on)
NDRBLXREG=1 : option for lateral boundary relaxation
               (0:explicit, 1: implicit)
```

Mapping and domain parameters

RPROJ	mapping projection index 0 for Mercater projection (MP) 1 for north polar stereographic projection (NPSP) -1 for south polar stereographic projection (SPSP)
RTRUTH	latitude where the map plane cuts through the earth's surface A north latitude for MP 60° for NPSP -60° for SPSP
RORIENT	domain orientation longitude
RDELX	grid spacing in meter in x-direction at TRUTH.
RDELY	grid spacing in meter in y-direction at TRUTH.
RCENLAT	reference latitude domain center latitude for MP 90° for NPSP -90° for SPSP
RCENLON	reference longitude domain center longitude for MP 0 for both NPSP and SPSP
RLFTGRD	a grid number in x-direction
RBTMGRD	a grid number in y-direction

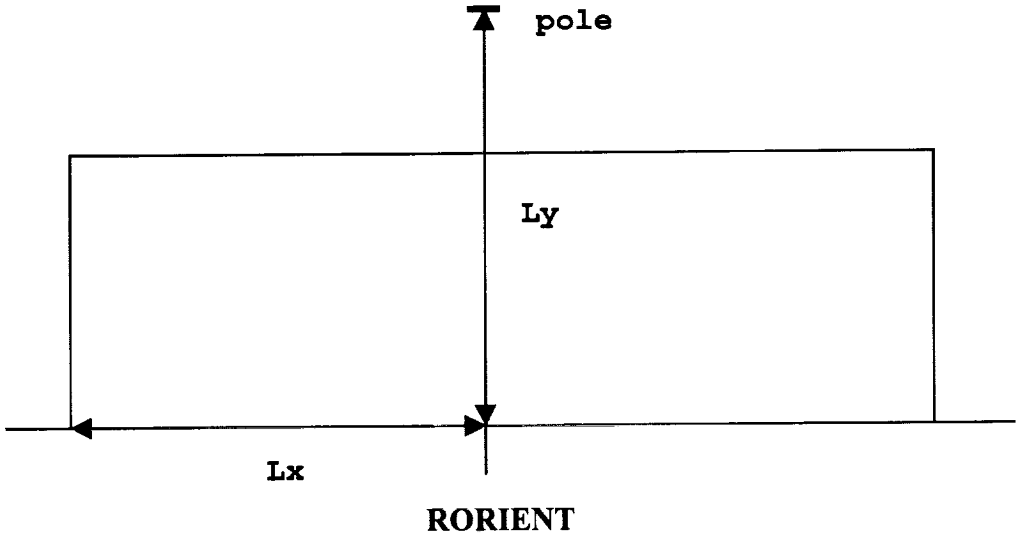
Calculation of RLFTGRD and RLFTGRD

1) Mercator projection



RLFTGRD = INT(Lx/RDELX)
RBTMGRD = INT(Ly/RDELY)

2) polar stereographic projection




```
RLFTGRD = INT(Lx/RDELX)
RBTMGRD = INT(Ly/RDELY)
```

A batch job parameters on IBM-SP

A parallel run with 4 processors

```
#
# @ job_type = parallel
# @ output = out.$(jobid)
# @ error = err.$(jobid)
# @ total_tasks = 4
# @ node = 1
# @ preferences = Feature == "dev"
# @ wall_clock_limit = 02:00:00
# @ class = dev
# @ queue
#
```

Appendix III. Hawaii Fire Danger User Manual

Purpose of this manual

The purpose of this user's manual is to provide entry level guidance to fire managers who are not familiar with the concepts and use of the National Fire Danger Rating System (NFDRS), as implemented in Hawaii. It is purposely non-technical. Those who wish to learn the details of the NFDRS should avail themselves of the National level 2 week training course held at the National Advanced Resources Training Center in Marana, Arizona, or of the voluminous written material resulting from both national and regional fire danger training courses. Neither is this intended to be documentation for a system manager. That has been provided elsewhere. The inquisitive user may wish to obtain the "S491 Reference CDROM for the National Fire Danger Rating System", as it contains voluminous fire danger rating references. Much of the material presented here was obtained from this source.

The first Hawaii fire danger system

The first attempt to develop a wildland fire danger rating system for Hawaii was completed in 1974 (Burgan, Fujioka, Hirata, 1974), with funds provided by the Hawaii State Legislature. This research indicated a significant fire problem, with an average of 14,000 acres of state protected forest and brushland burned annually, with the burned area ranging from 3,100 to 45,800 acres. Fires occurred on Oahu more often than on the other islands. The number of forest and brushland fires on Oahu ranged from 400 in 1967 to 1200 in 1972, with the largest burning 4200 acres. The largest fires, however, have occurred on the island of Hawaii. A fire in September 1969 burned 37,000 acres. The situation is similar for more recent years. For example, annual fire reports from the Division of Forestry and Wildlife show that the annual acreage burned (1994-1999), for their area of protection, ranges from 377 acres to over 37,000 acres, with an average of about 14,500 acres, much the same as in the 1970's.

The fire danger rating system implemented in 1974 was based on the 1972 National Fire Danger Rating System (NFDRS) (Deeming and others 1972) in use at that time in the continental United States. Fire weather observation stations set up on each of the major islands were used in conjunction with National Weather Service (NWS) weather stations to provide daily observations. These observations were channeled through the local NWS office on each major island and teletyped to the NWS Forecast Office at the Honolulu Airport, and also to the U.S. Navy's Fleet Weather Central at Pearl Harbor. Weather forecasters used the current observations to develop 24 hour forecasts that were also teletyped to Fleet Weather Central, where they were processed through the NFDRS program to produce various fire danger indexes. These indexes were then sent through the State Civil Defense Office teletype network to the Civil Defense, Police, Forestry and fire departments on the main islands and printed out in text format (fig 1). The structure of this system is shown in figure 2.

FOR HAWAII CIVIL DEFENSE
HAWAII FIRE DANGER INDEXES FOR 00Z 29 JAN 74

STATION	T	RH	FF	PPP	FFM	IC	SC	ERC	OI	BI	FLI
BARK SANDS	78	57	6	.04	8.2	37	7	9	37	2	0
KOKEE	57	93	2	0	23.4	0	1	0	0	0	0
LIHUE	78	65	8	.31	31.0	0	0	0	0	0	0
WAIALEE	77	69	4	0	9.9	28	3	8	28	1	0
WHEELER	78	54	8	.07	7.8	39	7	10	39	3	1
HONOLULU	75	64	8	0	31.0	0	0	0	0	0	0

Fig 1. Sample teletype output for the 1974 Hawaii Fire Danger Rating System.

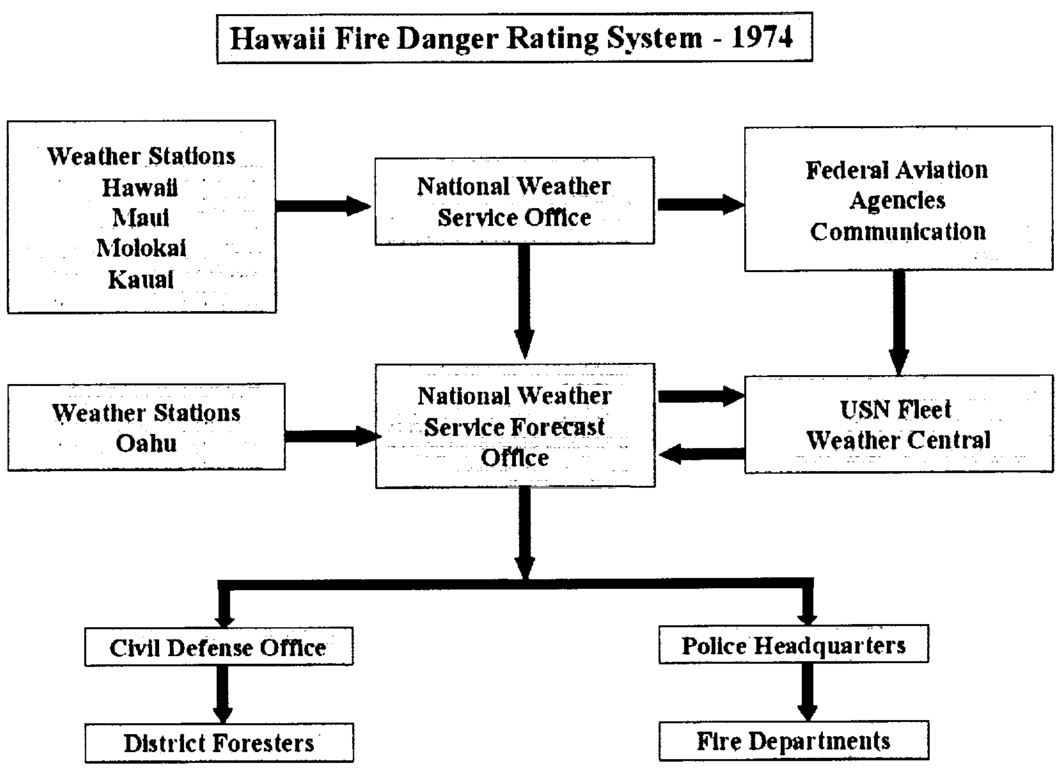


Fig 2. Structure of the 1974 Hawaii Fire Danger Rating System.

Unfortunately this system was difficult to maintain and fell into disuse after a few years. However, the need for a fire danger rating system continues and it can now benefit from improvements in weather data, communications, computational power, and fire danger rating technology.

The 2001 Hawaii fire danger system

The new Hawaii Fire Danger Rating System is based on the 1978 NFDRS (Deeming and others 1978) as updated in 1988 (Burgan 1988). The structure of the current HFDRS (fig

3) is much simpler than was the case for the 1972 system. All the processes from obtaining weather data, to doing the fire danger calculations, to disseminating the output fire danger index maps on the internet, can be accomplished by the Maui High Performance Computing Center and the Pacific Disaster Center. A few of the original fire danger indexes have dropped because they were difficult to maintain and interpret. The remaining indexes are more intuitive to the user.

The weather data is now derived from weather models that are run by the Maui High Performance Computing Center, rather than being observed from surface weather stations. This has the advantage of producing fire weather data at 2-4 km resolution, rather than just point observations from surface weather stations, where the point weather data is assumed to apply to some large, but largely undefined, geographic area. The assumption of course is that the modeled weather data is reasonably accurate.

The fuels data is much improved, having been derived from 1km resolution satellite data. This permits outputting fire danger maps on the internet, (http://www.mhpcc.edu/projects/wswx/) with 1 kilometer resolution – a significant improvement from the teletype output of the 1974 system.

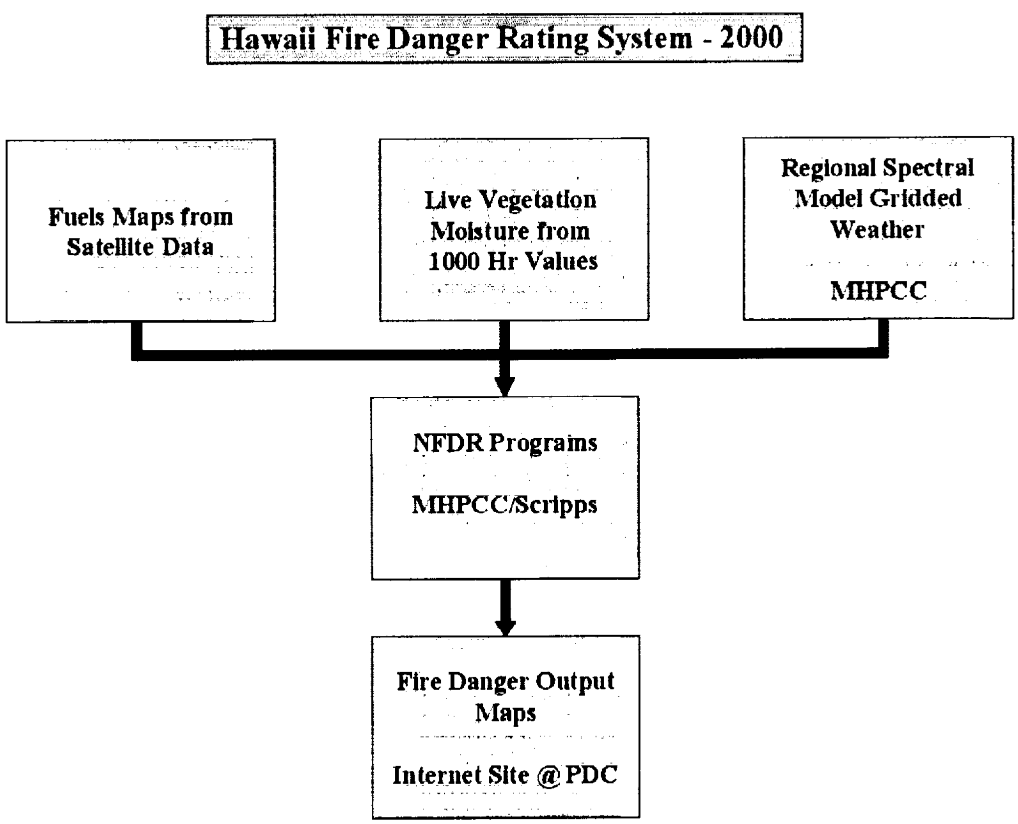


Fig 3. Structure of the 2001 Hawaii Fire Danger Rating System.

Basic Principles of Fire Danger Rating

Defining Fire Danger Rating

Fire danger rating combines the various factors of fuels, weather and topography to permit an assessment of the daily fire potential of an area. Fire danger is usually defined in numeric or adjective terms that can optionally be displayed in map form, which is certainly the easiest to interpret. The fire danger rating of an area gives the manager a **tool** to assess the day to day "fire business" decisions. The emphasis is on **tool** because fire danger rating information is not a final answer by itself; it must be considered along with the manager's local knowledge of the area and consequences of a decision when arriving at the best solution to a fire business problem. Fire danger ratings are typically reflective of the general conditions over an extended area, often thousands to tens of thousands of acres. Ratings can be used to guide decisions for future situations, subject to the limits of the forecasting system. If historical data is available, the severity of a particular day or season can be compared to others.

The difference between fire danger and fire behavior

Many of the inputs (fuels, weather, topography) and terminology (spread, intensity) that are part of fire danger rating are very similar to those used in fire behavior analyses, leading to confusion between the systems and misuse of the fire danger system. The principle difference is that fire danger is a broad scale assessment, while fire behavior is both site and time specific. That is, the two systems have very different spatial and temporal scales. Fire danger is calculated once a day from generalized inputs, and applied to large geographic areas. It is a "bookeeping" system in that it provides profiles of gradual seasonal changes in fire potential. The Fire Behavior System, on the other hand is just used for the duration of a fire, may be calculated many times a day using input data measured at the site of a fire, and does not provide a seasonal fire potential profile. Fire danger ratings describe conditions that reflect the potential, over a large area, for a fire to ignite, spread and require suppression action. Fire behavior on the other hand deals with an existing fire in a given l ocation. Fire behavior describes the movement (rate of area increase), fire intensity, flame length, and indicators of rapid combustion (spotting, crowning, and fire whirls) of that fire. It expresses a real time or predicted condition for ongoing fires. Fire danger provides a set of numbers that can be related to near worst case fire potential across large areas.

Key assumptions of the fire danger rating system

There are four fundamental assumptions associated with the National Fire Danger Rating System that must be understood if the system is to be properly applied and interpreted. They include:

1. It relates only to the potential of an initiating fire that spreads without crowning or spotting, through continuous fuels, on a uniform slope.

2. It measures fire business from a containment standpoint, as opposed to full extinguishment.

3. The ratings are relative, not absolute, and they are linearly related. In other words, if a component or index doubles, the work associated with that element doubles.

4. Ratings represent near worst-case conditions measured at exposed locations, at or near the peak of the normal burning period.

In summary, fire danger rating is a numeric scaling of the potential over a large area, for fires to ignite, spread, and require suppression action. It is derived by applying local measures of current or predicted fuel, weather, and topographic conditions to a set of complex science-based equations. The outputs are numeric measures that provide a tool to assist the fire manager in making the best fire business decisions.

Inputs

Gridded Data

In the typical fire danger rating application on the mainland, fire danger is calculated for specific weather stations that represent large geographic areas, and then assumed to apply equally to that entire area. The HFDRS is unique in that it utilizes gridded fuels, weather and topography data. Think of this grid as a matrix of small boxes spread uniformly across the Hawaiian Islands. Specifically that means that the fuels, topography and weather data are uniquely defined for each grid cell, thus permitting calculation of fire danger index values for each grid cell. The size of these grid cells is 1 square kilometer (about 230 acres) because the fuel model data has been determined to this resolution, and where other data is of lesser resolution, it is replicated to the 1km grid.

<u>Fuel Models</u>

A fuel model is a classification of the dead and live plant material representing a specific area. It reflects the amount of dead and live material (tons/acre), size (inches), depth (feet) and other physical properties of the fuel bed. Basically, fuel models describe vegetation in terms that are meaningful to the mathematical fire model used to calculate fire danger indexes. Because the variability of fuel bed characteristics is almost infinite, each fuel model in the fire danger rating system must necessarily represent a rather broad range of vegetation types. The key to fitting fuel models to vegetation is to select fuel models that can reflect both the magnitude and direction of seasonal and daily changes in fire potential. Fortunately for the users of the HFDRS, fuel model maps have been prepared in advance for each island group, through use of satellite derived vegetation data, mean annual precipitation data, and field consultations.

The vegetation data processing was performed by the Earth Resources Observations Systems Data Center (EDC) in Sioux Falls, SD. The vegetation data source was S10 synthesis data (10 day composites) obtained in1999 from the SPOT vegetation instrument. Thirty-six S10 NDVI images were calculated from the red and a near-infrared channel, then combined into monthly maximum value composites by combining groups of three 10-day composites. This helped remove cloud contamination. These images were masked for water through use of the global GTOPO30 data set. Barren land was masked by preparing an annual maximum NDVI dataset from the 12 monthly images, defining any pixel that was not water, and whose NDVI never rose above 0.2, to be barren. The vegetation data (less water and barren) was grouped into 25 classes through unsupervised clustering, then barren was added back to make a total of 26 land (vegetation) classes (fig 4). Notice that a small portion of the southern end of the Big Island, and the eastern side of Kauai show missing data. Fuel models were assigned for these areas without the guidance provided by the vegetation type map.

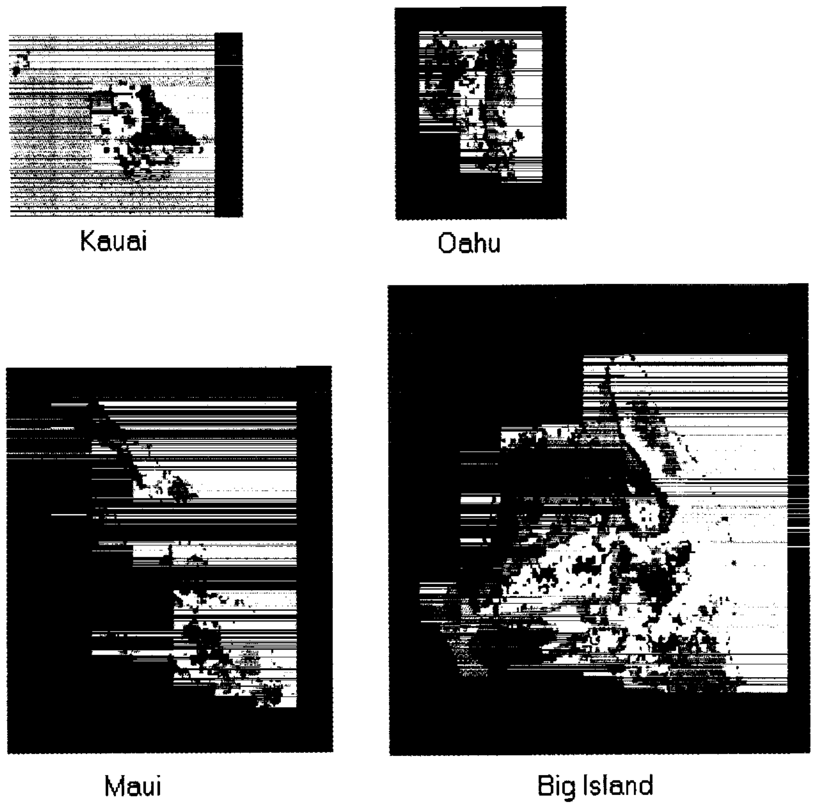


Fig 4. Vegetation cluster map, prior to conversion to NFDR fuel model maps

The vegetation map was reviewed by fire managers on each of the major islands and fuel model maps were produced by assigning nine NFDR fuel models to represent the 26 vegetation types. The mean annual precipitation map was used to define precipitation ranges for each fuel type when there was a need to separate an individual vegetation type into two or more fuel types. Pixels were individually assigned to specific fuel models when they could not be properly assigned by the combination of vegetation type and mean annual precipitation. The fuel model map for each island is shown in figure 5. These maps are used in place of the typical procedure of defining fuel types represented by individual weather stations.

Appendix III.2 contains a narrative description of each fuel model used in the HFDRS, Appendix III.3 displays the physical properties of each fuel model used.

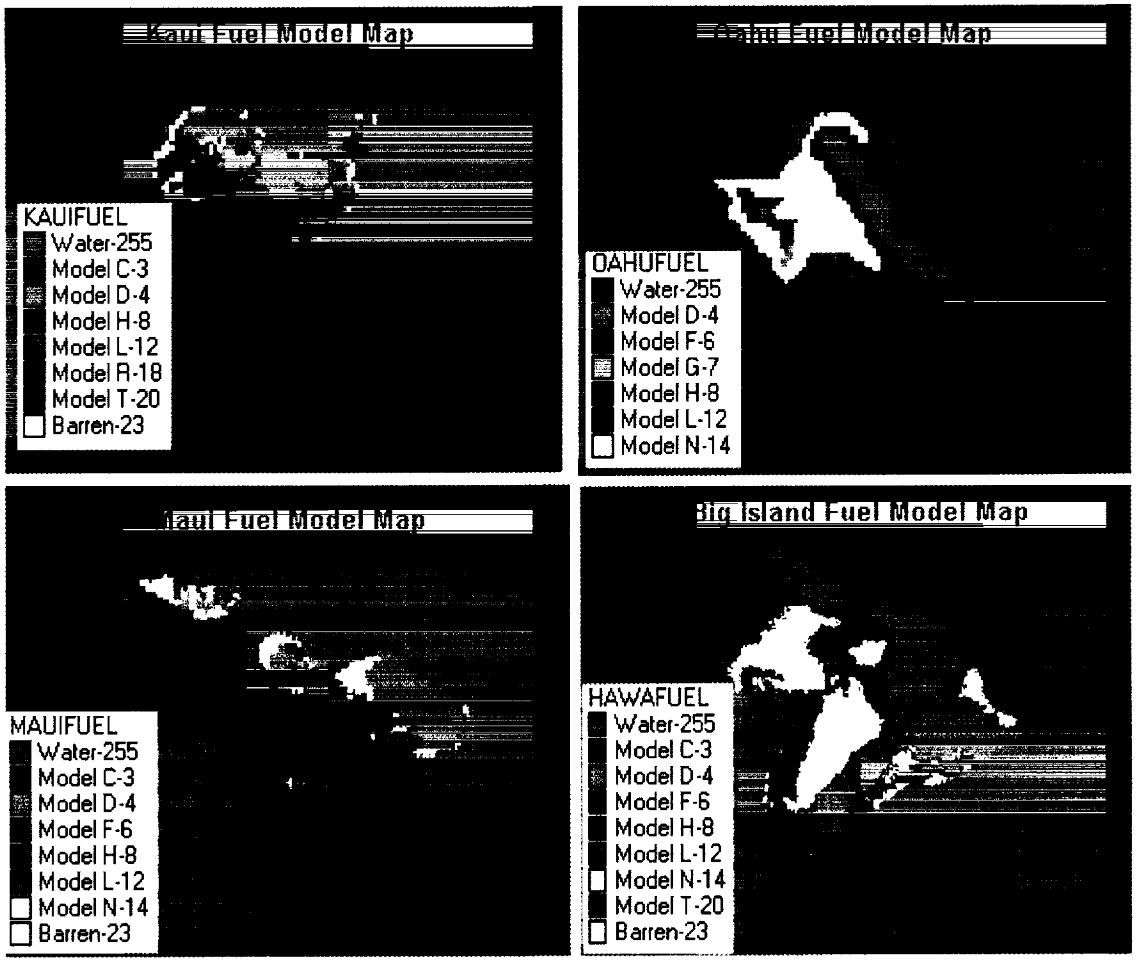


Fig 5. Fuel model maps used in the Hawaiian Fire Danger Rating System.

Slope:

Slope is the rise or fall in the terrain measured in the number of feet change per 100 feet of horizontal distance, expressed as a percentage. The effect of slope on fire danger can be noticable if the fuels are dry and slopes are steep, however wind has a much more significant effect on fire spread. Standard fire danger use is to categorize slope into 5 general classes, however for the HFDRS the slope is currently set to 20% because this is a reasonable value for most of the landscape, especially at a resolution of 1 km. Slope maps derived from digital elevation model data (fig 6), may permit better definition of slopes by defining an average value for each 1km pixel. This could be a low priority effort, but careful attention will be required to determine if this results in overprediction of fire danger in the areas of windward cliffs.

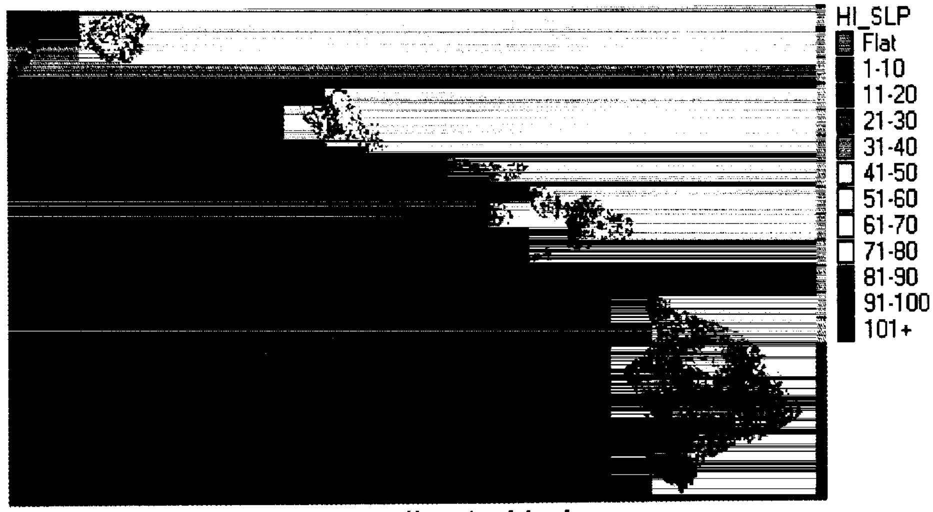


Fig 6. Slope map for the Hawaiian Archipelago

Mean Annual Precipitation:
This input is used for calculating the Keetch-Byram Drought Index (KBDI) (Keetch and Byram, 1968) as an adjunct to the standard fire danger outputs. The KBDI was developed in the southeastern United States to address the effect of long term drying, i.e. drought, on the forest soils and duff layer. Mean annual precipitation is used along with daily temperature and rainfall, to calculate daily KBDI drought adjustments. Mean annual precipitation, in draft form, is mapped for each 1km pixel (fig. 7) through data provided by the PRISM Climate Prediction Project, Oregon State University.

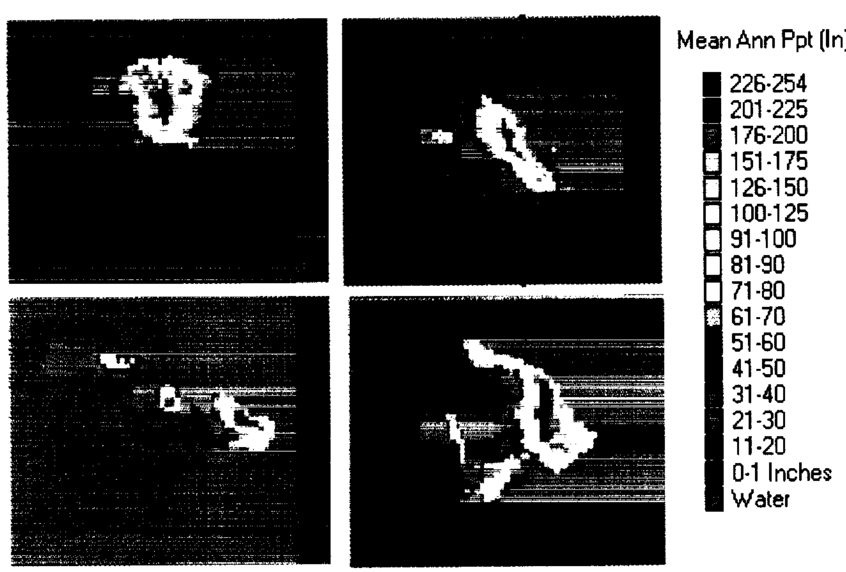


Fig 7. Mean annual precipitation (inches), by Island.

Weather Data:
Gridded weather data is obtained by running a "Gridded Spectral Weather Model" at the Maui High Performance Computing Center. Although this model can be run several times a day, the HFDRS only uses the 2:00pm (2400Z) weather maps because the

philosophy of fire danger rating is to approximate near-worst case conditions. The spatial resolution of the weather maps varies by island, being 2km for Kauai and Oahu, 3km for Maui, and 4km for the Big Island. In each case the weather data is replicated to 1km resolution so it will match with the 1km resolution data described above. Sample weather data maps are provided in figure 8.

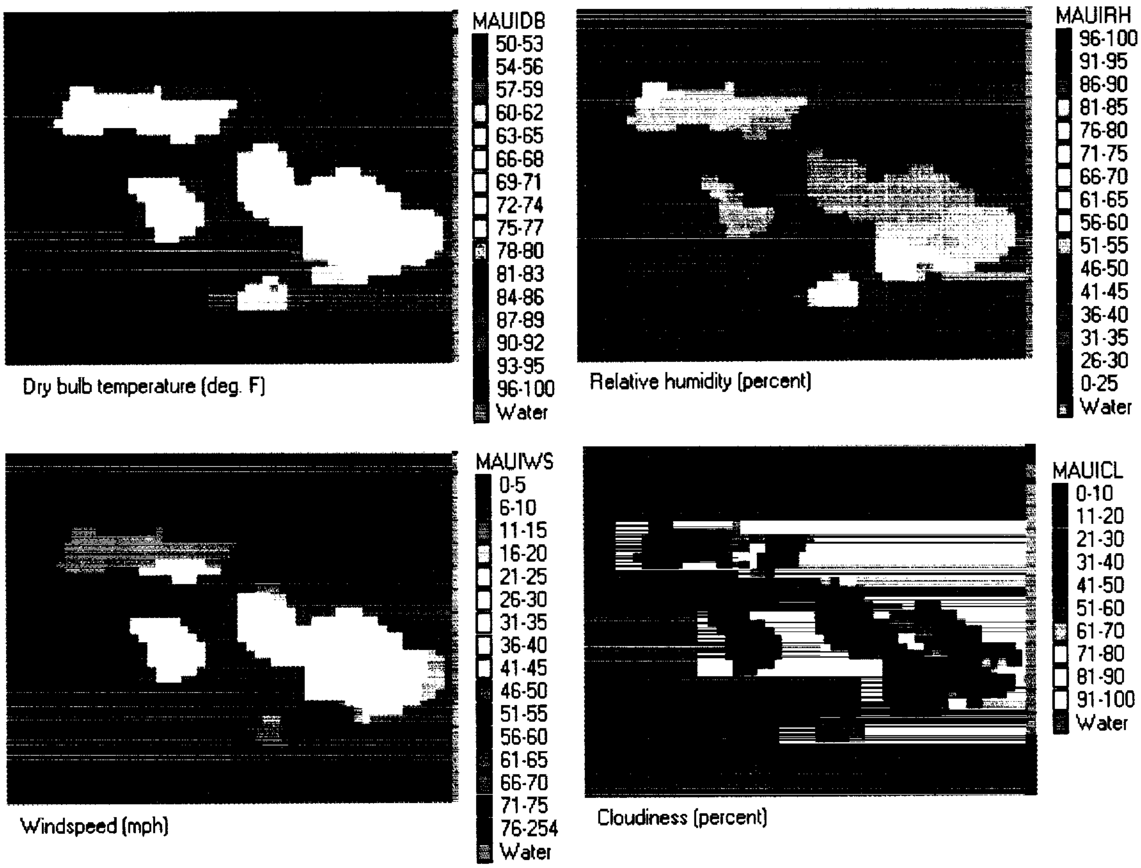


Fig 8. Sample daily gridded 1km resolution weather maps for Maui. Similar, and additional data is used to calculate gridded fire danger maps for all the major islands.

<u>Putting it all together:</u>
Much of fire danger rating literature discusses details of managing user controlled inputs and how they affect calculations. This is necessary for those who must run the fire danger rating system in the "standard" form, that is by inputting weather data from individual weather stations that must represent fire danger over large geographic areas. The situation is different for the HFDRS because there are no user controlled inputs. The standard user specified weather station inputs are replaced with either gridded map inputs, such as the mean annual precipitation map for example, or eliminated through simplification of the NFDRS computer program. Such simplification was possible because this system applies only to Hawaii, where it is not necessary to be concerned about winter v/s summer conditions, all the vegetation is perennial, etc. In addition, the user does not need to be concerned about maintaing weather stations and entering weather data because gridded weather data is provided by the regional spectral model. However, it is useful to at least be aware of the flow of input data and the general

processes used to produce the outputs. These are presented in figures 9 and 10. The Keetch-Byram Drought Index flowchart is presented separately both for clarity and because it is an "addition" to the standard fire danger outputs, and is discussed later.

It should be noted that the HFDRS does not output all of the standard NFDRS indexes and components. Such things as the human and lightning caused fire occurrence indexes, and the fire load index are eliminated because they are not particularly useful and they are very difficult to maintain. Only the most useful outputs have been retained.

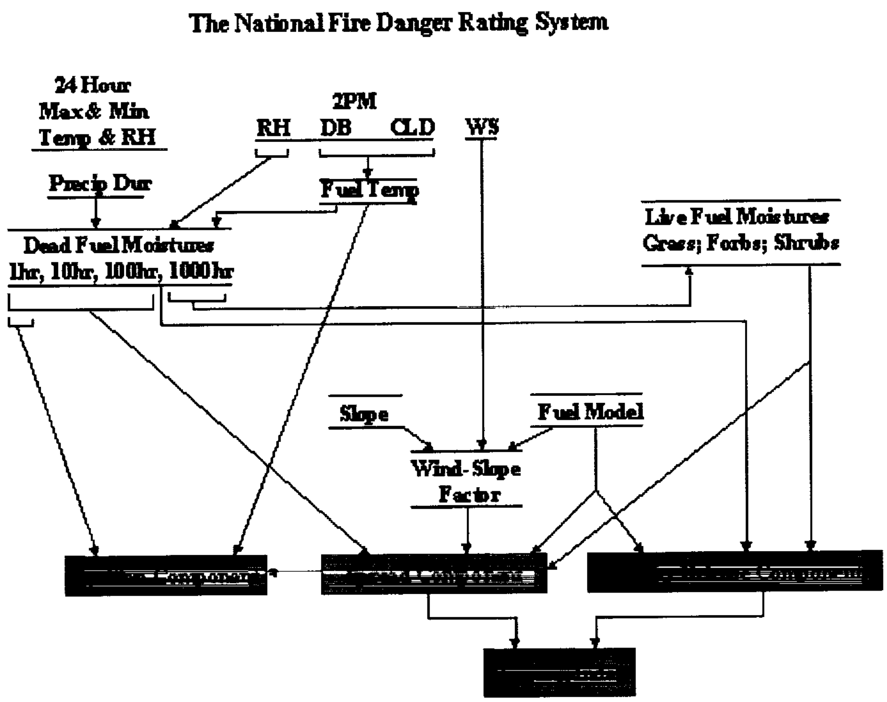


Fig 9. Flow of fuels, weather and topography data through the HFDRS.

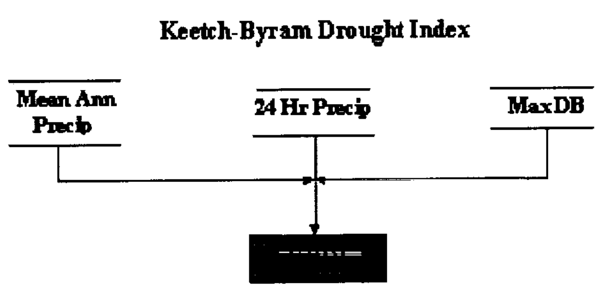


Fig 10. Data used to produce the Keetch-Byram Drought Index

System Outputs

Spread Component (SC)

The spread component is a rating of the forward rate of spread, in feet per minute, at the head of a fire. Thus a spread component of 30 means that the fire should be progressing about 30 feet per minute at the head. Flanking and backing fire spread rates are not estimated by this component. The SC is **very** sensitive to windspeed, and moderately sensitive to slope, especially if the fuel is dry. Because of its sensitivity to wind, the SC is highly variable from day to day, and in fact fire spread rate may be quite variable from almost minute to minute, but the HFDRS does not address this level of fire behavior detail. The SC is expressed on an open ended scale; it has no upper limit. Obviously the accuracy of the gridded windspeed data is critical.

Energy Release Component (ERC)

The energy release component is a number related to the available energy per unit area (BTU's per square foot) within the flaming front at the head of a fire. That is, if you think of a fire burning through one square foot of vegetation, the ERC is a measure of the amount of heat released from the time the head of the flaming front first enters the square foot area, until the tail of the flaming front leaves it. Daily variations in the ERC are due to changes in moisture content of the live and dead fuels. It is not affected at all by windspeed, thus it is reasonably stable from day to day. Because of this stability, it is one of the best indexes to provide guidance for those fire management decisions that should not be changed frequently, such as limiting public access to forest lands. The other index that is useful for this is the Keetch-Byram Drought Index.

The ERC can be considered a cumulative or "build-up" type of index. As live fuels cure and dead fuels dry, the ERC values get higher, thus providing a reflection of drought conditions. The scale is open-ended, and as with the other components, is relative. That is, a doubling of the ERC represents a doubling of potential heat release during a fire.

Burning Index (BI)

The burning index is a number related to the contribution of fire behavior to the effort of containing a fire. While the relationship is not mathematically exact, it can be thought of as closely related to the flame length, in feet, times 10. In other words, divide the BI by 10 to get an approximation of the flame length (in feet) at the head of the fire. The BI is derived from a combination of the SC and the ERC, so it is strongly affected by windspeed, and varies considerably from day to day. It has an open ended scale. Table 1 relates BI to flame length, with narrative comments relative to the affects on prescribed burning and fire suppression activities. It is important to remember that computed BI values represent the near **upper limit** to be expected if a fire occurs in the worst fuel, weather and topography conditions for this fuel type.

Studies have indicated that difficulty of containment is not directly proportional to flame length alone, but rather to the rate of heat release per unit length of fireline (Byram 1959). These data show that the containment job actually increases more than twice as fast as the BI values increase, so be forewarned.

Relationship of Burning Index to expected fire characteristics.

BI	Flame Length (ft)	Narrative Comments
0-30	0-3	Most prescribed burns are conducted in this range.
30-40	3-4	Generally represents the limit of control for direct attack methods
40-60	4-6	Machine methods usually necessary or indirect attack should be used.
60-80	6-8	The prospects for direct control by any means are poor above this value.
80-90	8-9	The heat load on people within 30 feet of the fire is dangerous.
90-110+	9+	Above this intensity, spotting, fire whirls, and crowning are expected.

Ignition Component (IC)
The ignition component is a rating of the probability that a firebrand will cause a fire requiring suppression action. Because it is expressed as a probability, it is scaled from 0 to 100. An IC of 100 means that every firebrand will cause an "actionable" fire if it contacts a receptive fuel. Likewise and IC of 0 would mean that no firebrand would cause an actionable fire under those conditions. Note the emphasis on action. The IC is more than the probablilty that a fire will start (given a firebrand), it has to also have the potential to spread. Therefore the SC values are part of the calculation of the IC. If a fire will ignite and spread, some action or decision is needed. Because the IC is a function of both the moisture content of small dead fuel, and windspeed, it has significant daily fluctuations.

Keetch-Bryam Drought Index (KBDI)
The KBDI is not a part of the original fire danger rating system, but was added during the 1988 NFDRS update. It is a stand-alone index that can be used to measure the affects of seasonal drought on fire potential. The acutal numeric value of the index is an estimate of the amount of precipitation (in 100^{ths} of an inch) needed to bring the soil back to saturation. A value of 0 is complete saturation of the soil, a value of 800 indicates totally dry soil. Because the index is calculated with the assumption that the upper soil and duff can contain 8 inches of water, the maximum KBDI value is 800. The KBDI's relationship to fire danger is that as the index value increases, the vegetation is subjected to increased stress due to moisture deficiency. At higher values dessication occurs and live plant material is assumed die, thus adding to the dead fuel loading on the site. Also, an increasing portion of the duff/litter layer becomes available fuel at higher index values. Two very useful papers describing how to use this index were written by Mike

Melton, and are reproduced in Appendix III.4. Because they were written for the warm, humid southeastern U.S, they should be reasonably applicable to Hawaii.

Application

Defining Fire Danger Classes

Typically, several years (at least 10) of historical fire danger indexes are analyzed for seasonal trends and correlated with actual fire occurrences to help set breakpoints defining the boundaries of fire danger classes – very low, low, moderate, high, extreme. Unfortunately, the historical fire danger data for Hawaii is limited to a few local weather stations operated by federal agencies, and this is not sufficient to define statistically valid breakpoints for fire danger mapped at 1km resolution across the state. There are two approaches to addressing this problem.

The first approach is to present the fire danger maps with 15 predefined classes for each index or component. Then, as a first step to relating calculated fire danger to actual conditions, fire managers must look at the fire danger maps daily, and relate their personal experiences and intuition of the fire danger with the various indexes and components. This not only provides an intuitive connection to the maps, it is also the fastest way to determine if the maps are reasonably portraying fire potential. To do this well, one needs to make this observation during rainy periods as well as dry ones, checking carefully to see if the fire danger maps look correct across all areas of the island, wet and dry. Although this is not quantative, it quickly reveals if serious discrepancies exist. This process should allow local fire managers to set standards for when various fire restrictions should be put into effect.

The second approach is to use Table 2, which presents adjective classes that were developed in 1974 by the U.S. Forest Service, Bureau of Land Management and various State Forestry organizations as a standard description for five levels of fire danger for use in public information releases and fire prevention signing. These two approaches are not mutually exclusive; both may be beneficial.

Table 2. Adjective Fire Danger Rating Classes.

Fire Danger Class	**Description**
Low	Fuels do not ignite readily from small firebrands, although a more Intense heat source such as lightning may start fires in duff or punky wood. Fires in open cured grasslands may burn freely a few hours after rain, but timber fires spread slowly by creeping or smoldering, and burn in irregular fingers. There is little danger of spotting.
Moderate	Fires can start from most accidental causes, but with the exception of lightning fires in some areas, the number of starts is generally low. Fires in open cured grasslands will burn briskly and spread rapidly on windy days. Timber fires spread slowly to moderately fast. The average fire is of moderate intensity, although heavy concentrations of fuel, especially draped fuel may burn hot. Short distance spotting may occur, but is not persistent. Fires are not

	likely to become serious and control is relatively easy.
High	All fine dead fuels ignite readily and fires start easily from most causes. Unattended brush and campfires are likely to escape. Fires spread rapidly and short-distance spotting is common. High intensity burning may develop on slopes or in concentrations of fine fuels. Fires may become serious and their control difficult unless they are hit hard and fast while small.
Very High	Fires start easily from all causes, and immediately after ignition spread rapidly, and increase quickly in intensity. Spot fires are a constant danger. Fires burning in light fuels may quickly develop high intensity characteristics such as long-distance spotting and fire whirlwinds when they burn in heavier fuels.
Extreme	Fires start quickly, spread rapidly, and burn intensely. All fires are potentially serious. Development into high intensity burning will usually be faster and occur from smaller fires than in the very high fire danger class. Direct attack is rarely posible and may be dangerous except immediately after ignition. Fires that develop headway in heavy slash or in conifer stands may be unmanageable while the extreme burning condition lasts. Under these conditions the only effective and safe control action is on the flanks until the weather changers or the fuel supply lessens.

Preplanned Dispatch
Most units preplan their actions in response to reported incidents. Logic says that the higher the fire danger, ther more production units necessary to contain the fire start. The question is which component or index best reflects the local unit's response needs. When historic fire danger data is available, comparison of fire sizes with corresponding SC, ERC, BI, IC and KBDI can give assistance in making this selection. Knowledge of the fire danger indexes at the fire location, coupled with experience in travel times and fireline production capacity for the various response alternatives, in the fuels and terrain in question, can help to shape the strength and type of response .

Public Use Restrictions
A problem often exists in determining when to initiate public use restrictions, which can be a very political action. The HFDRS should be quite helpful in this regard, once the level(s) at which to begin implementing restrictions are defined. Again, historical fire danger and fire occurrence databases are very helpful in associating fire occurrence with the indexes and components of the HFDRS, to determine which are most appropriate, and what the index values mean in terms of fire activity. The best that can be done to get started is to begin building a local database and begin making the associations as soon as possible.

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Appendix III.2– Narrative Fuel Model Descriptions

National Fire Danger Rating System fuel models presented here are those deemed most representative of Hawaiian vegetation. The vegetation types they represent are presented alonside the fuel model name, and a modified version of the standard NFDRS narrative description follows

Grass types

Model L – Grasslands of the lowest loading, such as grass-kiawe types.

This fuel model is meant to represent perennial grasslands where shrubs and trees occupy less than one-third of the area. The quantity of fuels in these areas is stable from year to year.

Model C - Moderately dense grass types such as molassas grass

Open stands typify Model C fuels. Perennial grasses and forbs are the primary ground fuel but there is enough litter and branch wood present to contribute significantly to the fuel loading. Some brush and shrubs may be present, but they are of little consequence.

Model N – Any very heavy grass type such as Fountaingrass or broomsedge

This fuel model was constructed specifically for the very dense sawgrass praries of south Florida. It may be useful in other situations where the fuel is coarse and reedlike. This model assumes that one-third of the aerial portion of the plants is dead.

Shrub types

Model D – False staghorn fern or other vegetation with about 60% live material.

This fuel model applies to heavy vegetation comprised of vegetation that is less than 1 inch in diameter and contains a significant live component that responds similarly to small live woody material, even though it may be heavy herbaceous material.

Model F – Continuous stands of brush such as pukiawe and/or aalii
Fuel model F represents mature closed chamise stands and oak brush on the mainland. In Hawaii it can represent continuous stands of moderately flammable shrub types such as pukiawe or aalii that have a strong component of small diameter live woody stems. This fuel model should represent vegetation that is not very flammable except in very dry conditions.

Model T - Grass-shrub mixtures such as discontinuous pukiawe and/or aalii
The shrubs burn easily and are not dense enough to shade out grass and other herbaceous plants. The shrubs occupy at least 1/3 of the site. Fires can be fast spreading.

Timber types
Model G – Eucalyptus or other forests containing large amounts of dead material.
Fuel model G is used for dense stands where there is a heavy accumulation of litter and down woody material. Such stands are typically overmature and may also be suffering insect, disease, wind or ice damage – natural events that create a very heavy buildup of dead material on the forest floor. The duff and litter are deep and much of the woody material is more than 3 inches in diameter. The undergrowth is variable, but shrubs are usually restricted to openings.

Model H - Healthy coniferous forests such as ironwood.
In contrast to model G fuels, model H describes a healthy stand with sparse undergrowth and a thin layer of ground fuels. Fires in H fuels are typically slow spreading and are dangerous only in scattered areas where the downed woody material is concentrated.

Model R – Hardwoods
This model represents hardwoods when the canopies are in full leaf It has 0.5 tons of fuel per acre in the 1, 10, and 100 dead fuel classes, as well as the live herbaceous and woody classes. It has no 1000 hr dead fuel. Thus it represents a rather lightly loaded fuel type and produces rather low fire danger indexes.

Appendix III.3 — HFDRS Fuel Model Parameters

Fuel model Parameters	**C**	**D**	**F**	**G**	**H**	**L**	**N**	**O**	**P**	**T**
Load (tons/acre)										
1-h dead	0.4	2.0	2.5	2.5	1.5	0.25	1.5	2.0	1.0	1.0
10-h dead	1.0	1.0	2.0	2.0	1.0	-----	1.5	3.0	1.0	0.5
100-h dead	----	----	1.5	5.0	2.0	-----	----	3.0	0.5	----
1000-h dead	----	----	----	12.0	2.0	-----	----	2.0	----	----
Live woody	0.8	3.0	7.0	0.5	0.5	-----	2.0	7.0	0.5	2.5
Live herb	0.8	1.0	1.0	0.5	0.5	0.5	----	----	0.5	0.5
Drought	1.8	1.5	2.5	5.0	2.0	0.25	2.0	3.5	1.0	1.0
Surface-area-to-volume-ratio (1/ft)										
1-h dead	2,000	1,250	700	2,000	2,000	2,000	1,600	1,500	1,750	2,500

10-h dead	109	109	109	109	109	----	109	109	109	109
100-h dead	30	----	30	30	30	----	----	30	30	----
1000-h dead	----	----	----	8	8	----	----	8	----	----
Live woody	1,500	1,500	1,250	1,500	1,500	------	1,500	1,500	1,500	1,500
Live herb	2,500	1,500	1,500	2,000	2,000	2,000	------	1,500	2,000	2,000
Heat content (all fuels, btu/lb)										
	8,000	9,000	9,500	8,000	8,000	8,000	8,700	9,000	8,000	8,000
Moisture of extinction (%)										
All dead fuel	20	40	15	25	20	15	40	30	30	15
Fuel bed depth (feet)										
	0.25	2.0	4.5	1.0	0.3	1.0	3.0	4.0	0.4	1.25
Minimum wind adjustment factor										
	0.3	0.4	0.5	0.3	0.3	0.5	0.5	0.5	0.3	0.6
Maximum wind adjustment factor										
	0.5	0.4	0.5	0.3	0.3	0.5	0.5	0.5	0.3	0.6

The Keetch/Byram Drought Index: A Guide to Fire Conditions and Suppression Problems

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The 1988 version of the National Fire Danger Rating System (NFDRS) has been completed and should be operational by the first part of 1991. The NFDRS has an important new addition: The Keetch/Byram (K/B) Drought Index calculations have been added to the system. As a part of the NFDRS, the K/B index will be the most widely used drought index for fire danger rating. Fire personnel will need to know specifically the effect of drought on both wildfire and prescribed fire and the significance of the index and its relationship to the fire environment. This means fire managers must understand the K/B index system, be able to interpret the data from the system, and apply that knowledge to the local fire situation.

The K/B Index

John Keetch and George Byram developed the K/B index at the Southern Forest Fire Laboratory to evaluate the effects of long-term drying on litter and duff and subsequently, on fire activity (1968). The index is based on a measurement of 8 inches (0.2 m), of available moisture in the upper soil layers that can be used by vegetation for evapotranspiration. The index measure is in hundredths (0.01) of an inch of water and has a range of 0 through 800, with 0 being saturated and 800 representing the worst drought condition. The index indicates deficit inches of available water in the soil. A K/B reading of 250 means there is a deficit of 2.5 inches (6.4 cm) of ground water available to the vegetation. As drought progresses, there is more available fuel that can contribute to fire intensity.

Fire Behavior at Selected K/B Levels

The following information is a compilation of data and observations fire managers and I have made from field observations of both wild and prescribed fire at numerous locations. It is an attempt to qualify and quantify in common terms the effect of continued drought on forest fuels and the problems arising from drought conditions during the course of wildfire and prescribed burns. This information should help fire practitioners to more fully understand the relationship between the K/B index readings—which indicate the extent of drought—and the fire environment.

As a part of the NFDRS, the K/B index will be the most widely used drought index for fire danger rating.

The effect of drought on fire behavior will vary between fuel types and topographic regions. Mountainous hardwood fuels will react differently than the Southern pine fuels to drought and consequently fire effects will also differ. Rain or relative humidity and wind may also require an adjustment to K/B level interpretation. For instance, even if the K/B level is extremely high, a brief rain will temporarily render fuels incapable of burning. Yet on the other hand, the K/B index can be low (<100) and high wind and low relative humidities can create an extreme situation in some fuel types. The following descriptions of conditions at various K/B levels is primarily related to the Southern Coastal Plain and Piedmont regions, but these can be considered applicable in many areas of the country. Fire personnel should remember that specific situations may be different than those described and should use this information to complement his or her experiences at a particular location.

K/B Levels 0–150. During this stage of drought, the fuels and ground are quite moist. Fine fuels exhibit daily drying, burning readily at times but also recovering to a high moisture content at night. This level is ideal for winter or spring prescribed burns. Most fires are easily suppressed with normal practices and generally are not a problem. The lower litter and humus layers are moist and not affected by fire. Most fires die out at night due to humidity recovery and its dampening effect on the fine fuels. Some fuel types (grasses) burn actively, but seldom create much problem with control efforts. Generally, extensive mop-up is not required, since most heavy fuels (100 and 1000 h) are too wet to ignite. Ignition of snags is not normally a problem on wild or prescribed fires. The spring fire season can still generate some extremes in behavior on wildfires due to the nature of fine fuels, especially in fuel types with a heavy loading of grasses. Drying is generally limited to the fine surface fuels and the organic layers still retain sufficient moisture to resist burning. This could be considered the business-as-usual period.

K/B Levels 150–300. Within this range, scattered patches of surface litter remain in low-lying or damp areas following a fire, and the organic layer remains basically undisturbed. Both pine and hardwood stumps may ignite but seldom burn below ground. Most will go out. Hardwood snags less than 10 inches or 0.3 meter in diameter at breast height may ignite and burn while larger snags (>14 in or 0.4 m) still resist deep burning due to high interior moisture levels. Generally snags are not a serious threat to control efforts, and most will go out during the night. However, snags within falling distance of the lines should be considered a major threat for potential fire escape. Normally, escaped fires pose little problem to standard suppression tactics. Fire behavior is predictable. Spotting is usually minimal.

When the K/B level exceeds 200 and approaches 300, a more intense and active fire situation develops, requiring closer attention by fire personnel. Usually at this level, minimum mop-up is required. Normal fire personnel and equipment levels are adequate, especially for most forest type fuel models. Wildfires can generally be suppressed with direct attack. Humidity recovery at night will aid in the control of fires during the night hours making suppression simple. Fire personnel should keep in mind that the 300 level represents the upper range that can be considered acceptable for normal winter or spring burning. Large acreages (500 acres or 202.4 ha) ignited at this level can create intense conditions that are difficult to control during the peak burning period and can do unnecessary damage to timber stands (scorch and bole damage).

A backing prescribed fire carried out when K/B index was below 100. Note absence of smoke following the fire. This indicates only fine surface fuels are being consumed and no deep burning of litter or soil organic layer.

Fire personnel should be especially careful with helicopter operations that ignite large areas of fuels simultaneously. Larger downed fuels will ignite, sometimes creating hazardous smoke conditions at night along nearby highways. Topographic features and drainages normally used for control lines can be expected to hold both wild and prescribed fires.

K/B Levels 300–500. At the K/B 300 to 500 level, fire consumes most surface litter along with a significant loss in organic soil material. Site preparation burns expose mineral soil, producing areas causing erosion problems. The heavier fuel complexes (100 and 1000 h) ignite readily, contributing to fire intensity. For instance, stumps are ignited readily and burn underground. Pine "lighter" stumps are totally consumed, but most hardwood stumps still resist deep burning, especially underground. Both pine and hardwood snags ignite at this level, although larger snags (20 in or 0.5 m and over) still resist deep burning. Hardwood snags ignite readily and pose control problems when located near lines.

Fire intensity increases dramatically in this range due to the increased burning of heavier fuel classes. Spotting begins to be a major problem and in some fuel types could be considered the rule. Escaped fire is difficult to control because heavier fuels are contributing to intensity, especially during the peak burning period. Fire behavior is still predictable but situations may require additional personnel and equipment to control a fire. Escaped fire in both prescribed and wildfire situations holds over during the night and burns again the next day. Humidity recovery is generally insufficient to extinguish heavier fuels, resulting in a large number of hold-over fires. Increased mop-up and patrol activities are required. All normally planned winter or spring understory fire should be canceled when the K/B index exceeds 350. Direct attack on wildfires is difficult due to intensity. Topographic features used for lines in prescribed fire and wildfire suppression will hold, but smaller drains begin to dry up, and drifted debris is dry enough to allow fires to creep across drains. Swamps begin to show reduced water levels.

K/B Levels 500–700. Generally, all surface litter and most of the organic layer is consumed by fire. Site preparation operations consisting of broadcast chemical application followed by fire ("brown and burn") result in almost complete removal of organic material from the site. At this level, 1000 hour fuels contribute readily to fire intensity.

When the K/B index is above 600, expect the following:

- Stumps burn to the end of the roots and all large downed fuels (logs and so on are totally consumed over a period of 48–72 hours. This will result in a massive amount of smoldering fire in the burned area.
- Dead snags ignite. Large dead snags will create a safety hazard due to the potential for falling.
- Dead limbs on trees ignite from sparks, sometimes at considerable height above the ground (50 ft or 15 m and over).
- Spotting is difficult to control.
- Escaped fire continues to burn through the night and into the next day.
- Burns leave excessive site damage.

Above the 600 K/B level, fire suppression is a major problem. Direct attack is generally not effective due to increased intensity and spotting. Extreme intensities add to the control efforts. When winds approach 10 miles per hour (16 km), spotting is the rule. Some nighttime activity can be extreme, dependent on fuels available. Fire personnel should expect and prepare for the previous day's fire to escape the next day during the peak burning period. Summer site preparation burns should be canceled when the K/B index reaches the mid-500's. Fire behavior is still predictable but tends to be underpredicted, since extreme intensity levels caused by the heavier fuel complexes might be overlooked. Extensive mop-up is critical to fire suppression. Increased need for fire suppression personnel and equipment can be expected.

As the K/B level approaches 700, understory vegetation wilts and is consumed by fire. All ephemeral drains and intermittent drains are dry. Only larger river drainages contain enough water to be useful in fire

A summer site preparation burn area, 1 year after an intense fire consumed basically all the organic layer, penetrating the mineral soil. The K/B index was over 600 at the time of the burn. Note almost total exposure of soil with no ground cover remaining and only one sprout showing control, and these are easily compromised by spotting. Most larger swamps will show significant water loss and intense fires can be expected if they occur in these areas.

As the K/B index goes into the upper 500 range, fire personnel can expect to encounter more urban interface type fire starts. Experience has shown that the general public is not aware of the volatile situation and more wildfire starts will tend to originate from "normal" burning by the public. At this point, only a major rainfall will reduce the fire hazard.

K/B Level 700 Plus. Expect more of the same, only worse! At the 700-plus level, many understory species with shallow root systems continue to exhibit extensive wilting and contribute to fire activity by acting as ladder fuels and increasing the chance of extreme fire behavior. All burning should be banned until the K/B index falls below 500, the minimum. Only rapid response time to wildfires along with intense suppression efforts will keep a major fire situation from developing. Most fire agencies and State organizations will issue burning bands on all outside burning, especially if wildfires have developed. At this K/B level, urban-interface fires become a major problem. Increasing numbers of wildfires originate from the vicinity of homes and residences since the general public does not adequately understand the care that must be taken in this kind of drought situation.

Additional Observations

There are two other conditions worth mentioning here that may affect the danger level as indicated in the K/B index. These are days-since-rain and humidity recovery. During the normal fire year, there will be a rise and fall of the drought conditions. The index is usually low in the spring and rises as summer progresses on into fall and then begins a slow decline as winter rains return.

Days-Since-Rain. During the early spring when the K/B index would normally show a level below 200, the days-since-rain number represents valuable information to the fire manager. If focusing on the drought index as a chief indicator for danger of wildfire occurrence, it is easy to forget that fine fuels readily burn and can create relatively intense conditions even at low K/B levels. At low K/B levels, days-since-rain is a better indicator of actual burning potential than the drought index. As the index rises into the 300 range and above, days-since-rain is of less importance because of the deep drying occurring in the lower fuel layers and in larger fuels with resulting increase in fire intensity. Very intense fires can occur in only 2 or 3 days following rain, if the drying of fuels is deep and requires significant moisture to saturate to near the moisture of extinction point. Consequently, the more advanced the drought, days-since-rain becomes less important. At this point, more emphasis should be placed on the K/B level.

Humidity Recovery. Humidity recovery normally happens to some extent each night. In the South, normal night humidities can average over 90 percent, while in the West 40 percent might be considered high. Regardless of the location, this increase in humidity has an effect on the availability of fuels to be consumed by fire. During the early stages of drought (below the 300 level), humidity recovery can actually control fires at night by raising the fuel moisture of fine fuels near or above the extinction level. Moisture is transferred from the atmosphere to the fuels and also from the lower fuel layers and soil which are very moist. As the drought increases, there is less moisture available from the lower fuel layers and soil and consequently fires can continue to burn through these deeper fuel layers at night. The resulting increase in fire intensity can effectively counter any increase in night humidity. Generally, as the K/B index approaches and exceeds the 500 level, humidity recovery alone will not stop the combustion process.

Summary

In review, and this is particularly true in the Southern States, normal spring or winter prescribed fires should be curtailed when the K/B index exceeds 350, and summer site preparation fire should be reduced when the K/B index exceeds 500. Wild and prescribed fires that occur when the K/B index approaches and exceeds 300 will cause increasing difficulty of control as the index goes higher. Wildfires that occur below the 300 level in fine fuel types or in steep topography can still be extremely difficult to control even though the soil and lower fuel layers are moist.

Fire personnel need to be especially cautious in using prescribed fire if the K/B index has been high and is falling into the upper 200-to-300 range. The heavier fuel classes will still be sufficiently dry inside to burn for extended periods and can result in smoldering fuels and subsequent smoke problems if near any smoke sensitive locations. Hazardous nighttime smoke conditions can reoccur for several nights. These heavier fuels will continue to smolder and burn until the next rain or until they are essentially consumed.

Fire personnel should be alert for K/B levels that depart from the normal precipitation yearly patterns, especially during spring or fall fire seasons. Figure 1 illustrates the typical K/B index readings for a year of normal precipitation. Figure 2 shows how the K/B readings in one period of the year can be used to predict fire danger later in the year. Spring fire seasons that coincide with increasing K/B levels of 300 and above can lead to increasingly hazardous fire conditions. Since most of the smaller fuel classes are cured at this time, they readily burn with increasing intensity as deep-drying continues. Likewise, fall fire seasons that coincide with K/B levels of 400 and above through October and November are usually busy seasons for fire personnel. Fall fires that occur during this situation will be extremely difficult to control and require extensive mop-up, since all of the fuel classes and soil were abnormally dry from the summer's heat, and fires will basically consume every class of fuel that can be ignited. For example, the fall fire season of 1987 had K/B level readings in excess of 700 through November, falling into the 600 level in December. Consequently, the spring season of 1988 was basically a carryover from the previous season with K/B readings in the 600 level common until mid-June in many parts of the South. ■

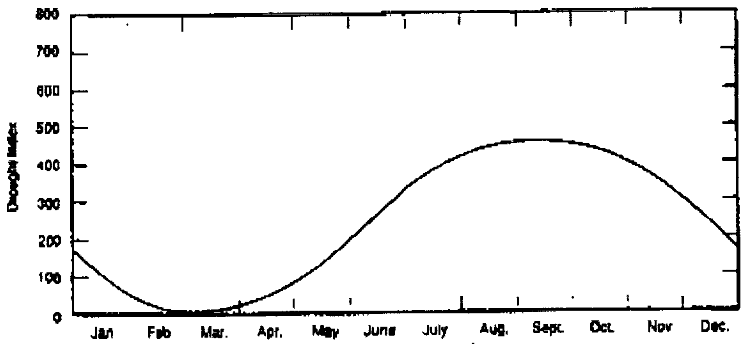

Figure 1—*A typical annual Keetch/Byram curve that can be expected with normal precipitation levels. (Actual levels may be different, depending on the locale, but the curve shape will be similar.)*

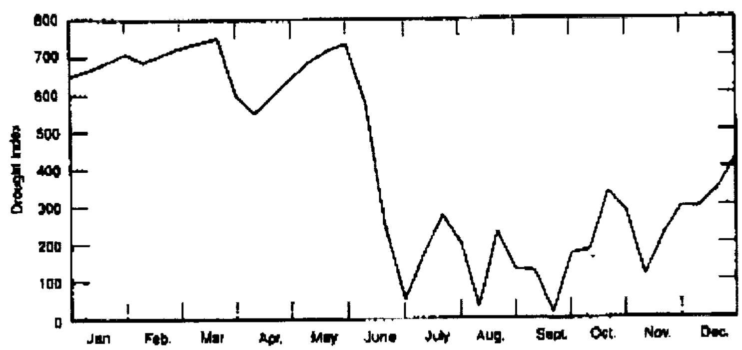

Figure 2—*A Keetch/Byram curve showing abnormally high spring readings. Situations such as this can result in extreme fire seasons in the spring. The reverse of this curve indicates the potential for a heavy fall fire season such as was experienced in 1987*

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Keetch-Byram Drought Index Revisited: Prescribed Fire Applications

Mike Melton

In volume 50, number 4, of *Fire Management Notes*, I contributed an article about the Keetch-Byram Drought Index (K-BDI), its relationship to fire suppression, and the problems that could be expected with suppression efforts at different levels of drought as measured by the index. Since that time, it has received many inquiries and comments appreciative of the practical information contained in the article. It has also been used as a training tool in a variety of fire management classes. I also learned that some wildland fire managers, especially in the Southeastern United States, have used the information found in the original article and applied it to prescribed burning. While the information contained in the original article is applicable to prescribed fire, there are some differences. With prescribed fire practitioners in mind, in this article I have expanded and addressed the K-BDI specifically from a prescribed fire perspective.

Keetch-Byram Drought Index (K-BDI) levels are calculated as part of the 1988 revisions of the National Fire-Danger Rating System (NFDRS) (Burgan 1988). Since the K-BDI calculations are simple, they are often made and kept by individuals or field offices that do not have access to NFDRS calculations or are not near an office that does.

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Drought indexes are not designed to measure fuel moistures, rather they indicate environmental conditions that affect fuel profiles.

To calculate the K-BDI values, users need a copy of the directions found in the original documentation (Keetch and Byram 1968) and a rain gauge. Then a simple mathematical process is necessary to determine the K-BDI value on a daily basis.

In the following discussions, I have addressed the index and effects on a drought scale difference of 200, which corresponds to the loss of 2 inches (5 cm) of water from the fuel and soil profile as the drought progresses from one stage to the next.

These following discussions are based on the fact that the seasonal variations in the index generally follow the southern seasonal temperature pattern. The index will be low in the winter and spring, increase during the summer and early fall, and taper off again in winter. In my conclusion, I discuss some of the variations found when the index departs from normal, some things to be expected from rising and falling indexes, and the days-since-rain concept.

K-BDI Levels 0-200

Much of the understory prescribed fire work in the South is done at the 0 to 200 levels, which correspond to the early spring dormant season conditions following winter rains. Soil moisture levels are high, and fuel moistures in the 100- and 1,000-hour fuel classes are sufficiently high, so these larger fuel classes do not significantly contribute to prescribed fire intensity in most cases.

Fuel moistures in the 1- and 10-hour classes will vary daily with environmental conditions. On any particular day, prescribed fires should be planned based on the predicted levels of moisture within these two fuel classes in association with weather conditions. Prescribed fire planners should be aware that areas with heavy loadings of these two smaller fuel classes can exhibit intense behavior resulting from the amount of fuel to be consumed. Also, areas that are influenced by slope and aspect can experience erratic and intense fire behavior from the preheating effects. Southern aspects can produce intense fire behavior while northern aspects of the same unit may have difficulty carrying the fire.

At the 0 to 200 levels, nearly all soil organic matter, duff, and the associated lower litter layers are left intact. These layers, even though they may not be soaking

Continued on page 8

wet, will be protected by the insulating properties of the moist layer below, will retain moisture levels close to extinction, and will resist ignition. Patches of unburned fuel can be expected with most fuel types. Burns conducted at this level can be expected to give the "mosaic" pattern of burned and unburned fuels over the burn unit, often a preferred result.

The typical burn patterns implemented at the 0 to 200 levels include a relatively fast head and strip-head fire or a backing fire that consumes the upper litter layers. Once the fire passes, remaining embers extinguish quickly. Within a few minutes, the area is completely extinguished and smoke free. Mopup efforts required on most burns are minimal. Burns that can be successfully implemented at this stage include those for fuel reduction, range improvement, or wildlife habitat, and any burn that does not require a deep burning, organic- and duff-reduction-type fire.

Smoke management concerns are primarily centered around the smoke generated during the burn and not from large smoldering materials following its completion.

Natural features such as creeks and drainages can be used as control lines. Most agencies and companies will use mechanized equipment to construct lines, but adequate lines can be constructed with hand tools. "Wet lines" can also be used in some fuel types.

A word of caution: While this part of the index represents the "wettest" part of the scale, it should not be taken as an indicator of fuel moisture (1-hour and 10-hour) in the upper layers of the fuel complex. These fuel moisture levels are totally dependent on fluctuations in daily weather variables. Dry air masses or frontal passages that pass over an area may have an insignificant effect on the K-BDI but can lower fuel moisture to critically low levels. Prescribed fire planners should ensure that acceptable fuel moisture measurements are accounted for prior to ignition, regardless of the K-BDI.

Management should consider that the mid- to upper-600 range is the limit of acceptability for igniting prescribed fires of any type unless specific locality conditions dictate otherwise.

K-BDI Levels 200-400

In normal years, the 200 to 400 levels would represent conditions found in the late spring and early growing season. Rising temperatures, increased levels of transpiration within the plants, and normal water movement reduce moisture within the soil and fuel profile.

In these index levels, lower litter layers and duff begin to show signs of water loss and will begin to contribute to fire intensity. Humidity recovery at night will have some positive effect on moisture recovery in the fuel profile. Daily temperature and humidity variations under normal burning conditions will quickly reverse this recovery.

Fire practitioners should expect an increase in fuel consumption over the area as the index moves into the upper end of this range. The increase in fuel consumption and resulting intensity can result in heavier fuel classes becoming involved in the burn. Heavier dead fuels such as downed logs and snags will now become a part of the burn process. Fire planners should also expect that some of the live fuels such as low-level brush species and vines such as honeysuckle may now receive sufficient heat to burn actively and contribute to control problems if they are close to fire lines. Patches of unburned vegetation are still common, but these conditions tend to allow for more smoldering and creeping fires that may eventually consume most surface fuels.

Fire planners wanting to initiate a burn over a forested area to "black it out" should consider the 200 to 400 range on the index as conducive for that purpose. Sufficiently intense fires can be generated with most forest fuel types to carry across the area. These conditions also allow for an increased, although not complete, consumption of the lower litter layers and duff, which tend to ensure the fire carries across the unit. Under normal conditions, the majority of the duff and organic layer will still be intact following the burn. Soil exposure will be minimal.

Smoke management can become a real hazard, especially if there are significant larger fuel classes available for ignition. Downed logs, stumps, and similar material should be expected to ignite and smolder for a considerable period of time. Also expect smoldering and the resulting smoke to carry into and possibly through the night. Smoke-sensitive areas should be thoroughly screened, and mitigation measures should be implemented when necessary.

Hand lines constructed to hold the fire should be composed of mineral soil. Managers should thoroughly check natural features used for control lines for drifted debris that could allow fire to creep across. They will need to patrol mechanical lines and clear away any ignitable materials left following construction. Fire planners should seriously reconsider line standards under conditions in the upper levels of this range.

K-BDI Levels 400-600

Levels between 400 and 600 are typical of those encountered during the summer and early fall conditions in the South. They represent the upper range at which most normal understory type burning should be implemented. Very intense fires can be generated with burns ignited in this range of conditions. Under these levels, most of the duff and associated organic layers will be sufficiently dry to ignite and contribute to the fire intensity and will actively burn. The intensity can be expected to increase at an almost exponential rate from the lower to the upper ends of this range.

Fire planners should expect a considerable amount of soil to be left exposed following a burn. Much of the site preparation burning done across the Southern United States occurs under this set of conditions. Intensity of burns under these conditions is such that most fuel classes occurring on a unit will ignite and burn. Complete consumption of all but the largest dead fuels can be expected. Larger fuels not consumed may smolder for several days, creating smoke and potential control problems.

Within the burn, expect weathered stumps, downed logs, and most snags to be completely consumed over a period of time (possibly several days). A significant portion of the duff and organic layer will be consumed, resulting in large areas of exposed mineral soil. These areas may be susceptible to sheet erosion with the next heavy rain. This potential varies with soil types. Smoke management relating to sensitive areas is of critical importance due to the length of time smoke is likely to result from the burn area.

Under normal circumstances, fire planners should have a specific resource management objective that requires an intense fire before igniting understory fires in this range. The intense fire and deep burning that often result from these conditions can do serious damage to timber resources and present an opportunity for insect pests to create additional problems. Control problems resulting from spotting should be expected.

These 400 to 600 levels indicate two things are happening: 1) Deep drying resulting from water loss is occurring in the duff and organic material in the soil, and 2) lower live fuel moistures resulting from continued water loss in the soil and the natural physiological process within the plants make understory vegetation susceptible to ignition with a minimum of preheating. These two situations amount to an increase in the fuel available for consumption and consequently increase the fire's intensity. Fire planners should consider that the outputs from computer programs and nomograms relating to intensities are underpredicted and plan accordingly.

At these levels, fire planners should seriously begin to reevaluate the line construction and location standards necessary to contain the burn. Reduced runoff levels in some drainages can preclude their use as control lines or require that they receive some refurbishment treatments. Failure to pay attention to low water levels and debris that has drifted into creek channels can create potential control problems that will continue to escalate as the index levels increase because fires can creep across such materials. Where practical, use either major natural features or roads that are suitably located. All line construction should be of mineral soil. Since duff and organic material can provide an avenue for fire to burn across the line, it is imperative that it is removed from within constructed lines. Where practical, consider line locations that would otherwise be used for fire suppression; they can give an added "edge" in maintaining the security of the lines under intense conditions.

K-BDI Levels 600-800

The 600 to 800 range of the K-BDI represents the most severe drought conditions identified within the index and results from an extended period of little or no precipitation and high daytime temperatures.

There may be exceptional cases when specific management objectives for a given area justify prescribed fire ignitions within this range. Management should consider that the mid- to upper-600 range is the limit of acceptability for igniting prescribed fires of any type unless specific locality conditions dictate otherwise. These levels of the index are often associated

Continued on page 10

with increased wildfire occurrence, and many States and municipalities will issue burning bans when the K-BDI is this high. Burning bans, of course, should preclude any management decision regarding prescribed fire. Such bans are an acknowledgement of the seriousness of the fire situation.

Prescribed fires ignited within this range will be characterized by intense, deep-burning fires. The potential for significant down-wind spotting should be considered the rule in planning. Live understory vegetation 2 to 3 inches (5 to 8 cm) in diameter at ground level should be considered part of the fuel complex because live fuel moistures will be sufficiently low and the vegetation will burn easily with a minimum of preheating. The majority of soil organic material subject to ignition will be consumed; stump roots and other subsurface organic material that ignite will probably be completely consumed. Once ignited, large fuel classes will burn intensely with almost total consumption. In brief, expect these fires to be very difficult to contain and control.

Possibly a year or more will pass before a layer of organic material will be replaced on the area. Resource managers should expect some amount of soil loss from erosion until the area replaces sufficient vegetative cover. The significance of the loss will be determined by the specific soil type and slopes on the area. Line construction standards should follow the previous discussion standards.

Rising and Falling Indexes

This discussion primarily addresses the effects on the larger dead component fuel associated with a given fuel model and has its basis in the timelag concept associated with 100-, 1,000-, and 10,000-hour fuel classes. Indexes that have been low and begin the normal seasonal rise are characterized by the larger fuel classes being damp deep inside. Typically, a large piece of woody material will be saturated in the interior and therefore be difficult to ignite and sustain combustion. As time progresses, the exterior dries, but interior fuel moistures still remain high. For example, smoldering logs are sometimes ignited by fire intensities high enough to overcome the surface moisture levels but later go out due to the high interior moisture levels, precluding further combustion. When this occurs, there may be some concern about smoke from the smoldering debris and mop up. Dealing with this situation is relatively easy because humidity recovery at night can help extinguish this type of ignition. However, a falling index can cause an opposite reaction.

The larger fuel classes have experienced deep drying from a sustained period of little or no precipitation. The exterior surface may have a relatively high fuel moisture level from recent rain while the interior of the fuel will have lower moistures due to the longer equilibrium timelag. Prescribed fire ignited under these conditions may develop sufficient intensities to break through this outer layer of high fuel moisture. Once this happens, the fire encounters a reservoir of material with comparatively low fuel moisture levels and can be expected to burn for an extended period of time. This could go on for several days within the area and result in a large amount of smoldering material and smoke management problems, depending on the type and amount of fuels on the area. Experience has shown that this material will continue to smolder until it is consumed, mopped up, or another precipitation event raises moistures to a level of extinction. The resulting smoke problems can be compounded by fluctuations in wind direction over several days. Mop-up operations can be lengthy and expensive.

Fuels that have high moisture levels on the outside and are dry on the inside should be expected for indexes that have been in the 600+ range and have rapidly fallen into the 200 to 300 range. This could have resulted from one precipitation event, and while the 1- and 10-hour classes of fuel are immediately affected, the other fuel classes are slower to react. This is just one example of the subtleties noted from actual field experience in dealing with the index values.

Days Since Rain

Finer fuel classes are immediately affected by precipitation of any type. Since fires originate and spread within these classes, we can use this characteristic to accomplish prescribed fire objectives during what might normally be unacceptable drought conditions.

During the first few days following precipitation, the surface fuels will have been saturated and begun to dry out. The lower fuel layers and possibly even the organic layer may still have moisture-of-extinction levels. Resource objectives can be accomplished by timing the burn to occur during this period even though the drought index levels may still be high. Timing of the prescribed burn may be critical and fire planners should be fully aware of the conditions they are dealing with. Most burns should be accomplished during the first 2 or 3 days following precipitation. From a prescribed fire standpoint, the effects of precipitation will have disappeared after about 4 days of continuous drying.

Prescribed fire personnel should be especially careful in monitoring the amount of precipitation that has occurred. Once fuels have experienced deep drying, there must be a significant amount of rainfall to dampen conditions to the point where they are reasonably safe for burning. In most cases, precipitation amounts in the 1/2-inch (1.3-cm) range should be considered minimal. The prescribed burning of dry, fine fuels affected by small amounts of precipitation reflect the type of conditions and burning done in the summer growing season throughout much of the Southeast. These burns can be accomplished by careful planning and following these general guidelines.

Index Readings That Depart from Seasonal Norms

Fluctuations in weather patterns, temperatures, and precipitation levels can all coincide to create a departure from the normal yearly index pattern. An abnormally dry fall and winter season could lead into an early spring season with drought index readings in the 500 to 600 range. For example, in 1987, the Southern United States experienced a severe fall fire season and carried K-BDI readings of 600 into January and February 1988, when the normal reading would be expected to be less than 100. Since that time, other localized drought events have occurred, resulting in similar fire seasons.

Prescribed fire planners must recognize departures from normal readings in planning burns for their particular location. A burn conducted under index levels of 100 in the springtime is not the same as a burn conducted under levels of 500. Extreme caution should be used in implementing any burn under this set of conditions; they are primed for a potential escape situation.

The ideal time for understory prescribed burning in the South is within the first 2 or 3 days after precipitation.

Closing Thoughts

Through the previous discussion, I have attempted to qualify and quantify the effects of the K-BDI as it relates to the application of prescribed fire. The variables within this application are many and their interactions complex.

Prescribed fire personnel should always remember that the K-BDI is a measure of meteorological drought; it reflects water gain or loss within the soil. It does not measure fuel moisture. Prescribed fire application is almost totally dependent on the moisture levels in the 1- and 10-hour classes, which must be measured by other means for an accurate assessment of fuel moisture, regardless of the drought index readings. Prescribed fire managers must also be aware that dry vegetation due to reduced soil moisture will create additional fuels available for fire consumption in the mid and upper ranges of the index. This condition is not accounted for in current computer technology such as BEHAVE (Andrews 1986).

The K-BDI levels discussed here and the resulting effects on prescribed fires should not be considered hard-and-fast rules but rather a reflection of my career experiences in dealing with both wildfires and prescribed fires and the levels of the K-BDI. Readers are invited to develop their own guidelines and apply this information to their particular situations. Variations in fuel types, topography and aspect, geographic location, moisture and temperature regimes, and soil types may dictate a variety of effects within the levels of the K-BDI. After all, that is why we describe the implementation of prescribed fire as an art rather than a process.

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Appendix IV. Hawaiian MM5 Forecast Manual

Introduction

MM5 is probably the most popular mesoscale weather model and is used in research worldwide. It was developed at the National Center of Atmospheric Research in Boulder Colorado, and at Penn State University. It is an evolving model, with a new version appearing every year or few years. The MM5 is state of the art using the most up to date meteorological research for the model's formulation and set up. The Hawaiian forecast uses the most recent version as of 3/01. For more information on MM5 refer to the MM5 home page:

http://www.mmm.ucar.edu/mm5/mm5-home.html

The Domains

6 different domains are used in the Hawaiian forecast. Each domain covers a specified area that is run at particular horizontal and vertical resolutions within MM5.

1) The outer domain (**fig 1**) has a 27 km horizontal resolution. It is the largest domain, a 4860 by 4860 km square centered on the Hawaiian Islands. This domain is designed to simulate the larger scale features that affect the islands, for example frontal passages, and tropical disturbances.

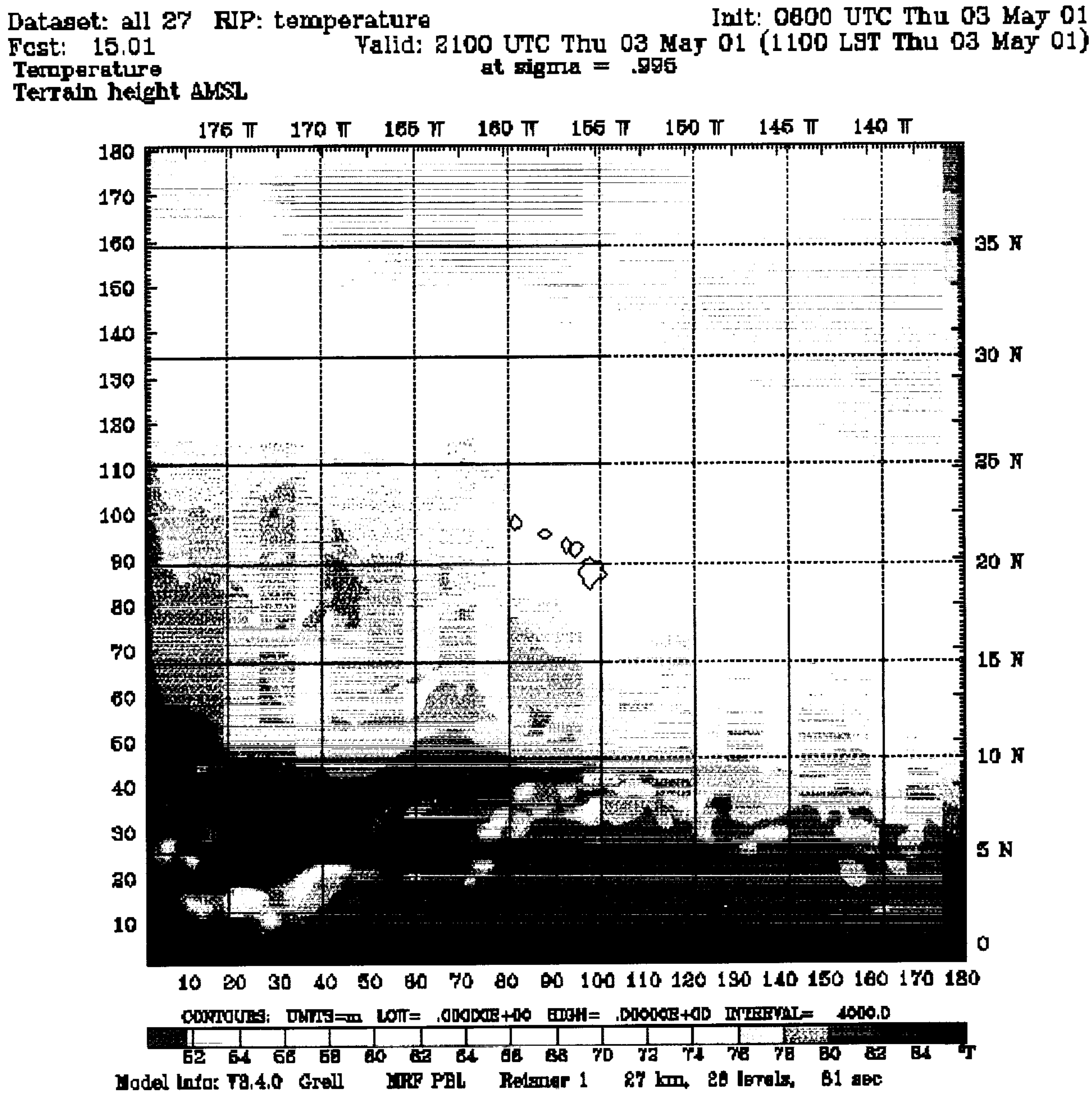

Figure 1: 27 km resolution domain, temperature plot

2) Within the outer domain is a 9 km resolution domain that covers the region surrounding the near vicinity of the Hawaiian Islands (**fig 2**).

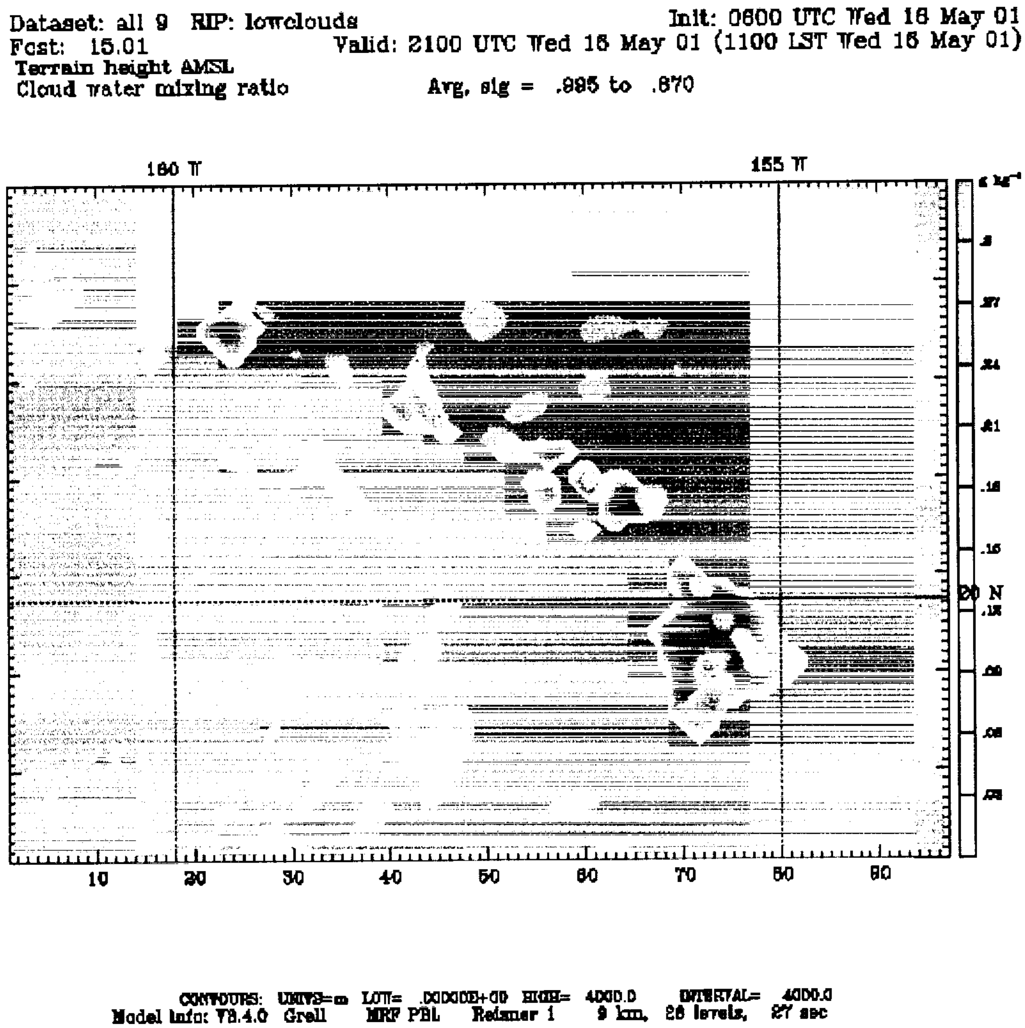

Figure 2: 9 km resolution domain low cloud plot

3) There are then four 3 km resolution domains over a)Kauai and Nihau, b)Oahu, c)Molokai, Lanai, Kahoolawe, and Maui (**fig 3**) d)The Big Island.

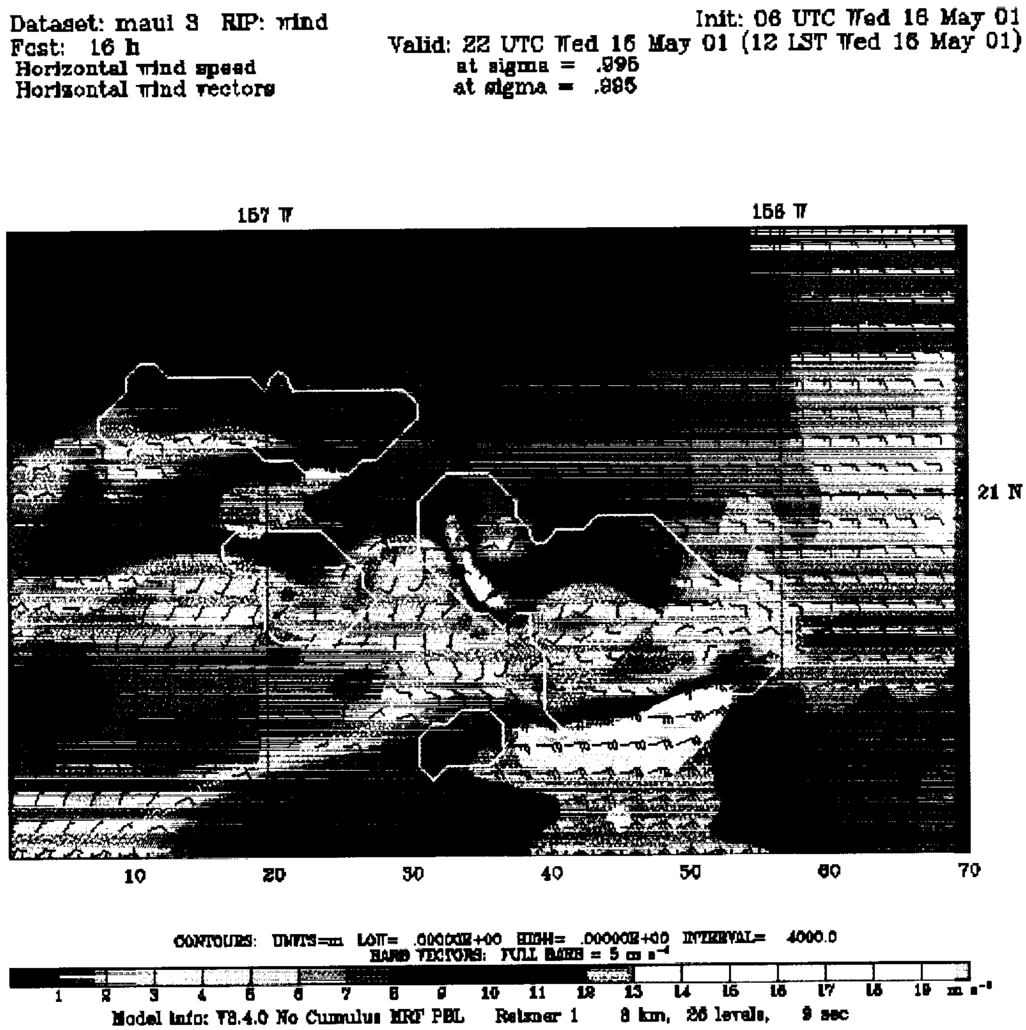

Figure 3: 3 km resolution Maui domain, wind strength and direction

4) Finally at present a 1km resolution domain over the Haleakala region on Maui, not currently available on the web site.

Website structure

The MM5 home page first allows the user to select one of the 6 domains to view. After selecting the domain of choice the user can choose a field to view. There is a choice of viewing either an animation over the forecast time or a specific field at a particular time. The model data is archived.

The Fields

a)Temperature (see fig 1): The temperature field provides the temperature at the lowest level of the model. This can be considered as the equivalent to the temperature at 2m above the ground. The temperature is in degrees Fahrenheit and the color scale is at 2 degrees intervals.

b)Wind (see **fig 3**): This plot shows the strength and direction of the wind at the 2-meter level. The color plot is the wind speed in meters per second. The wind speed in knots is approximately twice the value.

c),d),e) Low (see **fig 2**), middle, and high clouds: The representation of clouds in MM5 is sensitive to many factors. Different cloud and microphysics schemes are used for different studies and each scheme makes different assumptions. For the Hawaiian forecast we use the Grell cloud scheme with the Reisner mixed phase cloud microphysics scheme. For the 3km and 1km resolution domains only the Reisner microphysics scheme is used.

Clouds are plotted on sigma levels. Sigma coordinates are terrain following coordinates as shown in **fig 4**. For this reason the low, middle, and high layers are dependent on the elevation of the surface. For the complex topography of the Hawaiian Islands it is important to note that over the mountains the clouds in the low level field will only be low relative to the surface, that may be as high as 4000 meters.

The clouds are defined by the cloud water mixing ratio. For the low, and middle cloud field, clouds(grey shading) are plotted at mixing ratios greater than 0.05 g/kg. For high clouds the grey shading is for mixing ratios greater than 0.01 g/kg.

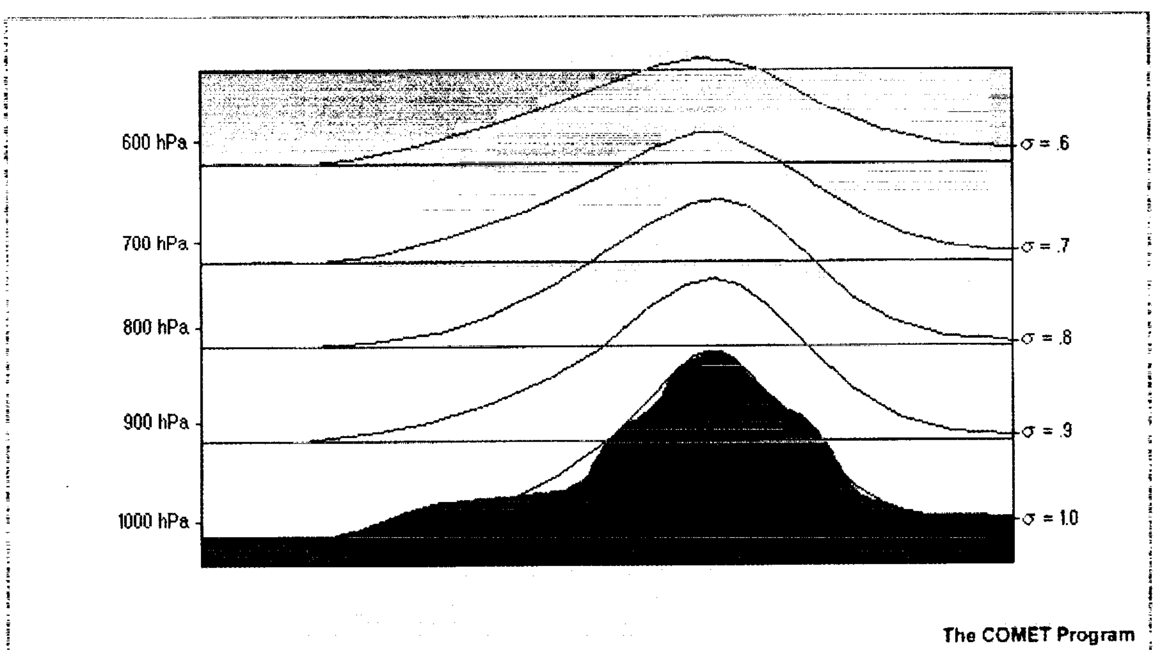

Figure 4: Sigma coordinates over mountainous terrain

f)Relative Humidity: This plot has relative humidity at the surface in %.

g)Rainfall: This plot has the accumulated model rainfall over the past three hours before the specified time. The rainfall is in mm.

Haleakala Domain

Within the 3km resolution domain covering the island of Maui, a 1km resolution domain is nested over the Haleakala volcano region. The summit observatories are providing observational surface data for 6 stations within the region at the locations shown on **fig 5**. These observations will be assimilated into the forecast thereby hopefully improving the accuracy of the model in this region. This is particularly important given the high resolution of the domain.

Figure 5:° The Haleakala region with the surface stations (red dots)

This domain is designed to provide the observatories with primarily cloud cover data as well as the other meteorological conditions.° Establishing cloud cover in such a high resolution domain may be a difficult task given the complex daily cycle and topography.° We hope to be able to validate the model results by using the observations for Haleakala.

West Pacific Domains

We have the ability to provide MM5 forecasts for specific islands in the west Pacific. These islands include Guam, Pohnpei, American Samoa, and Eniwetok. The resolution of domain around each island would most likely be 3km. The island domains would then be nested in a 9 km, 27km, and finally a 81 km resolution domain covering the West Pacific region.

Appendix V. Answers to specific PDC questions about: High-resolution weather forecasts/analysis (J. Roads, PI, jroads@ucsd.edu)

http://ecpc.ucsd.edu/projects/pdc/pdc.html

0. Description of your Project

Since the beginning of this NASA PDC project, we have routinely provided global to regional to mesoscale numerical model output to the PDC for various applications. In particular, we now provide high-resolution numerical model output for predicting environmental conditions associated with diverse natural hazards such as wild land fires, drought, El Nino/Southern Oscillation (ENSO), VOG, and severe storms. We are also developing corresponding archives that can be used to evaluate temperature, precipitation, wind, humidity, fire potential, and drought predictions for the Hawaiian Islands as well as the entire Pacific Basin as part of our Scripps Experimental Climate Prediction Center (ECPC).

Since the Scripps ECPC hosts the current RSM/MSM model master, the MSM/RSM models are available to PDC upon request. MM5 is also available from NCAR. However, we did not plan to actually provide the RSM/MSM (or MM5) models since this would require some high-level modeling expertise to develop, execute, and analyze what we now do routinely for the HWCMO forecasts and the other Scripps ECPC forecasts. However, if PDC has the resources to efficiently utilize these models they are more than welcome to them and we will be glad to help them implement them as part of the PDC system.

1. Status of your project

The RSM/MSM has been run routinely since the start of a research grant (9/1/1999-8/31/2001) through NASA's Natural Hazards PDC program. Initially the RSM/MSM forecasts were made out to only 24 hours but during the PDC grant timely RSM/MSM forecasts were extended to 48 hours (since 4/2001) and could be easily extended to 72 hours depending upon available computer time. Also, the initial meteorological forecasts were augmented by fire danger and drought forecasts and are also now being utilized to drive VOG tracer models. The output is also available for other models requiring routine high-resolution meteorological data.

Experimental 28-hour MM5 forecasts have also now been implemented routinely (since 4/2001) to provide an alternative model prediction. Development of associated fire danger and drought predictions as well as model archive and evaluation with MM5 have not yet begun but in principle can be done if output from that model is also required in the future.

In addition, we have held several workshops with PDC personnel.

1. We described our basic operational system at the first PDC PI meetings at PDC, 12/8-9/1999 (Roads et al. 1999).
2. We held a training session for PDC personnel on 4/17/2000 at MHPCC. At this training session, we described the HWCMO model, products, and available research deliverables to PDC personnel.
3. We held an RSM workshop for the entire international RSM community and interested PDC personnel at MHPCC, Jul. 17-21, 2000. At this workshop, our RSM/MSM

modeling system was described in extensive detail by the developers and our numerous international collaborators (Roads 2000b)

4. We further described the operational system and available products at the 2nd PDC PI meetings at PDC, 1/17-19, 2001 (Roads et al. 2001).
5. Another RSM workshop was held this year in Taiwan and another one is being planned for next year in Los Alamos New Mexico.

2. How you have met milestones to date, and what remains to be done

We have basically met all of our milestones, although we are still trying to develop a better analysis and documentation and are continuing to work on this, at least until the end of this contract. The user manual and this appendix are online at: **http://ecpc.ucsd.edu/projects/pdc/pdc.html**

Milestones:

1. *High-resolution weather forecasters/analysis products.* The RSM and MM5 forecasts/analysis will continue to the end of the PDC contract (8/31/2001). A final report, including a user manual describing the system and associated output will then be delivered to PDC. (It is unknown yet whether the routine forecasts will continue past this end date since there has been no resolution as to what kind of support will be needed to continue the forecasts. We will certainly do our best to not stop any forecasts, although some issues really need to be resolved to ensure continual delivery.)

2. *Enhance standard HWCMO forecast / analysis products with a drought index and fuels based fire-danger rating.* The Hawaii fire danger and drought rating has now been implemented and is displayed and provided along with the basic meteorological variables to PDC.

3. *Evaluate and compare HWCMO forecasts with observations and other models.* This is an ongoing effort. Initial evaluations are described in the HWCMO user manual (in preparation).

4. *Develop an open MP version of the current HWCMO MSM.* This has now been implemented and is described by the HWCMO user manual (in preparation; see the web site above). Open MP has increased single processing speed by 300% and if computer expense were not an issue then timely 72 hour and even longer forecasts would now be possible every day. Due to budget and MHPCC support limitations, we have only increased the RSM/MSM forecast time to 48 hours under the current contract.

5. *Include an open MP version of MM5 in the current HWCMO GSM framework.* This has now been implemented and routine MM5 forecasts and forecast displays are available, for at least the meteorological data. Additional work will be needed to have the MM5 forecasts drive the fire danger, drought and vog transport models and this will probably not be finished by the end of the contract.

6. *Work toward developing similar models and products for Guam, American Samoa, and Pohnpei.* This part of the effort was never explicitly implemented, in part because a

number of other problems took higher priority, and in part because another island needing such forecasts was not identified by PDC. However, given the ease we have had in developing the current models for the individual Hawaiian Islands, we see no problems with developing similar models for any other island, when and if PDC really desires such a model setup. In that regard, we have also met this milestone.

3. We are very interested to hear about your model's integration into PDC. If you are providing new data sources (rather than model code), please review how PDC will gain access to these data.

Input data for the MSM and MM5 forecast models is provided via Internet (ftp) from NWS National Centers for Environmental Prediction and from Scripps ECPC. The mesoscale models (MSM and MM5) are subsequently run at MHPCC and the MSM now drives a fire danger code as well as vog transport calculations. Website graphics and model output data, including GIS output, are have been made freely available to PDC and we are now sending files over daily. In addition we have archived input data and forecast output since the beginning of this contract to present at MHPCC.

PDC has been notified about this data access and they were asked to comment about the output. Our initial feedback indicated that they would rather have us ftp them the daily data than to have us open up our disk files for them to access. We are in the process of fully implementing this. However, we would encourage PDC to develop a more general access within the model environment in the future.

4. Model Acceptability:
Please summarize any coordination or collaboration activities that have occurred - or are planned - between your modeling project and the Federal agency that has the responsibility for issuing watches, warnings, and advisories. For instance, if you have a weather model, how can we get NOAA's assistance in validating the model? Or if you have a volcano product, what plans do you have for working with USGS/HVO to get their acceptance of the model? Also, describe any sensitivity or validation studies that have been performed or are planned.

Besides working with modelers at NCEP, which provides the numerical guidance for all regional weather forecasts in the country, including the local Hawaii weather service, we are using standard NOAA (MSM) and Air Force (MM5) models. We utilize NCEP analyses to initialize the models and NOAA observations to validate the models. The major distinction from the NWS and Air Force is that we are extending these models to higher spatial resolution and longer time scales. Our model output is then made available to the National Weather Service and other agencies through at least the Internet Website. It should be noted that operational forecasters of NWS choose what model information they wish to utilize in the preparation of advisories of severe weather. In that regard, the Hawaii Weather Service is making use of a very similar lower-resolution (10 km) version of the MSM that we are using for these experimental (higher resolution) forecasts The unique advantage of our output data is that it can be used to provide enhanced digital detail for all severe weather and climate events but ongoing evaluations of its accuracy as well as the additional value added for specific events still needs to be objectively evaluated.

Also, describe any sensitivity or validation studies that have been performed or are planned.

We are developing long-term archives of the model forecasts and available observations to understand some of the model biases as well as skill. Preliminary studies described in the user manual indicate that the skill is high and comparable if not greater than standard weather, climate, and fire danger forecasts. Given this model skill, we are now in a unique position to be able to develop high-resolution climatologies and weather forecast archives for the Hawaii Islands that can be used to supplement meager weather observations.

In addition, we are extending the model to even higher resolution for various case studies. As described in the user manual, Oahu weather simulations were developed on a one-kilometer grid for a small-scale field experiment on August 14 and 16, 2000.

5. Model Adaptability

Please describe the steps or process involved in adapting the model to different regions within the PDC Areas Of Responsibility (AOR). Weather models, for instance, may work well in the northern hemisphere but require significant modification to work in the southern hemisphere. Also, comment on any code modification, model calibration, or other considerations required in the adaptation process.

Our mesoscale models are driven by operational NWS global analyses and forecasts; as such, they are re-locatable anywhere on the globe. However, the regional domain, including high-resolution terrain and surface files, must be specified in the model set-up. This regional data is available globally for all model resolution and thus the models can be easily ported anywhere in the world.

It should be noted that our models are used internationally (we have sponsored the international RSM workshop the past 3 years, for example) and we have thus gained some experience upon the adaptability of the models for different regions.

However, evaluating the predictions and simulations for a particular region requires detailed local knowledge, and thus it is always our preference to work with local researchers on local problems. In that regard, we have focused in this contract on the Hawaii Islands.

6. Model Assumptions:

Please describe the physical process modeled, assumptions that have been made, and how the process is implicated within the code. Also, discuss the operational limits and constraints of the model. Comment on what disclaimer information should be added to a PDC output product resulting from a particular model or suite of models.

We provide high-resolution forecasts and analyses of the weather, as well as applications of this weather and climate information for fire danger. These forecasts are higher in resolution (order of magnitude) and extend further in time, than what is available from the NWS. Digital products from these forecasts are also used to drive application models, which have heretofore only used meager available observations as input.

These forecasts are thus intended to be a major supplement to what is available from official agencies, such as the NWS, which is tasked to provide operational weather forecasts. However, the weather service is aware of what we have been doing and is supportive. In that regard, I should mention that NOAA has supported our experimental prediction work for over 20 years. Many of our efforts have not only resulted in scientific publications but have also gone into improving our nation's ability to deliver increased amounts of and increasingly more accurate weather and climate forecasts.

However, the disclaimer on our web site says
EXPERIMENTAL PREDICTIONS SHOWN IN THIS SITE HAVE NO OFFICIAL STATUS. OFFICIAL FORECASTS ARE DISSEMINATED BY THE NATIONAL WEATHER SERVICE AND OTHER GOVERNMENT ORGANIZATIONS.
PDC should provide similar notification if it wishes to provide similar products.

7. Data - Input:
Please identify the model input data requirements. Providing a handout with a list of the following would be useful: Note that we expect that your final delivery to the PDC will have documentation that describes how the model utilizes the data, so that an early discussion of these issues may help you formulate the final version.

RSM/MSM model documentation in the user manual includes detailed information about input routines. Basically, the input data comes from the NCEP global analysis and aviation forecasts that are available every day at NCEP. These analyses and forecasts are obtained by ftp every day from the NCEP rotating disk archives. Separate documentation is provided for the fire danger code, which utilizes the basic output of the RSM/MSM. In addition, several static files describing the model orography, vegetation, and land-sea masks are needed for specific islands and these are included with the models.

Only more general documentation is provided for the more experimental MM5 model, since this experimental model was set up only at the end of the contract and in general all detailed input data provided for the RSM/MSM are also used for the MM5.

8. Data - Output:
Please identify and comment on the model output data for potential PDC products.
Digital daily high-resolution weather data is available to drive all application models requiring weather information. For example, our output data drives a fire danger and drought code as well as a transport model for vog. Output from these application models is also available to PDC. These application models can also be used to make predictions since our mesoscale models predict all weather information at lead times of 2 days (now) and eventually could make forecasts of 3 or more days depending upon available computer time.

Also, include information on:

a) **Data type:** digital high-resolution regional weather data
b) **Format:** IBM binary and text files, some in GIS output format.
c) **Resolution:** 80 kms for input NCEP analyses, 10 kms for all islands run. 2-4 kms for individual islands.
d) **Accuracy:** comparable to observation error for initial fields, decreasing accuracy with increasing lead time
e) **Data size:** 150 Mb/day
f) **Perishability:** All input and output data have been archived on the MHPCC mass storage system since the beginning of the project and will be readily available through the end of the project. After that, it is not clear what MHPCC will do with the data.

9. Hardware and Software Requirements:
Please describe the model host or execution platform (PC, UNIX, SGI, CRAY, SP, etc.). Please describe any supporting hardware and software required for model development, maintenance, execution, output display, and data visualization.

We have found that a dedicated supercomputer center can be important for our task although it is certainly quite possible to run similar codes on a dedicated high-end UNIX workstation, which we actually do for other domains. There are in fact some advantages to using high-end workstations and these advantages should be weighed along with the advantages from super computer centers. For example, if MHPCC was willing to help with needed computer time and effort for this project then ways for PDC and MHPCC to continue this collaboration should be explored. If MHPCC wants to charge commercial rates then it is our feeling that cheaper alternatives like high-end workstations might prove more economically feasible for PDC.

Please describe any supporting hardware and software required for model development, maintenance, execution, output display, and data visualization.

The models use standard Fortran and C compilers, along with UNIX scripts. Products are provided as digital files to standard graphics packages, such as NCAR graphics, GRADS, GMT, and GIS. These digital products can be downloaded and easily displayed on high-end PCs, Macs, and low-end workstations.

10. Cost:
Please describe any licensing, maintenance, data, run-time, or other costs associated with the model.
All model licenses are free. All input data is free. All output data is free except for the intrinsic cost of producing it on various computers. Display output can be low or high cost depending upon the cost of the desired graphics environment. However, it should be noted that the major cost is the time and effort involved to run a large weather prediction model. A dedicated and knowledgeable person or more is required to sustain the effort. For example, our RSM/MSM model master was in charge of upgrading the Hawaii RSM/MSM to open MP, as well as upgrading the HWCMO WEB site, etc. MHPCC programmers as well as other scientific staff also provided some help in adapting the model to the MHPCC framework.

In the research phase, we have been taking advantage of a number of people to develop and maintain the models. To adequately maintain the present level of activity, we would require support for at least a full time model master to monitor the jobs, data archive, and web displays, as well as some additional scientific support. An adequate workstation or access to supercomputer time would be required. We estimate a continued cost of around 100-150K/year depending upon computer costs (supercomputer or workstation) and personnel.

In short, the current effort demonstrated the feasibility of making these routine forecasts; now the question is what it would really take to sustain it.

11. Model Run Logistics:

Comment on where the model software will be located.
The Scripps ECPC now maintains the basic RSM model software and updates. The specific versions used for the PDC project are located at MHPCC. The basic MM5 software is maintained by NCAR and the specific Hawaii version is located at MHPCC. The fire danger code is online at MHPCC and is also available through the Scripps ECPC as well as the USFS. All of these codes are continually being upgraded and the latest versions would be available to PDC.

Comment on what expertise is needed to run the model.
High-level programming skill coupled with meteorological expertise are needed for the mesoscale weather models. The fire danger code (which includes the drought prediction) is more general and can be run with less expertise but needs some fire danger expertise to interpret and analyze it.

Comment on the typical scenario run times.
Current single processor runs take 12 hours per 48 hour all island forecast and 24 hour individual island forecasts. With transfer to 4 processors open MP, the run times have dropped by a factor of 3 and runs up to 72 hours are certainly possible every day if computer costs can be covered.

Comment on identifiable thresholds or conditions for initiating the model run.
We believe it is most useful to run the model every day but to then access it for other applications on a case-by-case basis. We do not believe this type of complicated model can be run on a case-by-case basis except as a special study after the fact. In that regard, it should be noted that typical case studies like this will take several years to complete and would not provide timely forecasts and analysis for PDC applications.

Please describe any data interdependencies with other modeling projects.
We are not dependent upon the other projects to deliver our data. However, we could use some help in evaluating our products. Some projects such as vog and pollution transport models are using our data to drive aerosol transport and diffusion models and we hope this can continue.

12. Analyst Training:

Please describe the level of analyst training required for effectively using the model. If you have started to prepare your manual, please bring draft materials. Note that the User Manual that you are preparing should explain:

a) How to ingest new data

b) How to build a scenario

c) How to run the model

Training as a mesoscale atmospheric modeler is required to continue to run these mesoscale codes. In addition, the modeler would require some time to get used to our basic operational environment, including learning how to download the needed input data on a routine basis and how to display and analyze the output data. Our standard RSM user manual describes this in complete detail.. The MM5 user manual, which explains similar things, is also available from NCAR. Both of these explain 12a-c. In short, our user manual describes the current data input and output from these models as well as how to run the fire danger code. These can serve as a beginning point as well as point of reference for later operations. In that regard, it should be noted that during this contract, we have held 2 RSM workshops in which the first day was devoted to a first course on the RSM and the subsequent days introduced ways in which the RSM was being used by the international community. A competent modeler should be able to become fully acquainted with the modeling system within a year.

Even if PDC only desires the output products, we also believe it would be helpful if someone from PDC were to spend some time at Scripps ECPC or MHPCC learning about available products and suggesting ways in which we could improve data delivery of current products. Alternatively it would be useful for us to spend some time at PDC accessing our output and tailoring the output products for specific PDC needs. For example, we could hold periodic training courses on specific output requirements including ways to analyze, interpret, and display weather and fire danger output. In that regard, we held one specific workshop describing the basic system and have since been in contact with various PDC members on the best way to transfer the basic data to PDC. We believe that interested PDC researchers would require only a few weeks to months to begin accessing and displaying our output data.